BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	**)**	
	)	**WT Docket No. 11-65**
Applications of	**)**	**DA 11-799**
AT&T Inc. and Deutsche Telekom AG	**)**	
	)	
for Consent Assign	**)**	
or Transfer Control of	**)**	
Licenses & Authorizations	**)**	

JOINT DECLARATION OF JEFFREY H. REED AND NISHITH D. TRIPATHI

I am Professor Jeffrey H. Reed. I am the Director of Wireless @ Virginia Tech and the Willis G. Worcester Professor of Electrical and Computer Engineering at Virginia Tech University. Wireless @ Virginia Tech is one of the largest and most comprehensive academic wireless research groups in the US. I am an author or co-author of over 150 peer-reviewed journal and conference papers and the co-author of three books. Early in 2011 my fourth book will be published by Wiley and IEEE, Cellular Communications: A Comprehensive and Practical Guide, with Dr. Nishith Tripathi. This book is based on the classes we teach at our respective organizations. I am also the President of Reed Engineering, a wireless engineering consulting firm with which Dr. Tripathi is also affiliated. I am a Fellow of the IEEE and past recipient of the College of Engineering Research Award. I have served on the technical advisory boards of many companies and have approximately 30 years of industrial and academic experience.

I am Dr. Nishith Tripathi. I am a principal consultant at Award Solutions, a provider of technical consulting and specialized technical training for wireless communications. My students include senior personnel from companies throughout the wireless industry and other wireless engineering instructors. I specialize in a variety of technologies, including as IS-95, CDMA2000, 1xEV-DO, GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, HSPA+, WiMAX, and LTE. I received my doctorate in Electrical and Computer Engineering from Virginia Tech, and I have held several strategic positions in the wireless arena. As Senior Engineer for Nortel Networks, I gained hands-on experience analyzing and optimizing the performance of CDMA networks, in such areas as capacity, handoff and power control algorithms, supplemental channel management algorithms, and switch antenna diversity. As a Senior Systems Engineer and Product Manager for Huawei Technologies, I worked on the infrastructure design and optimization of CDMA2000, 1xEV-DO, and UMTS radio networks. I am the co-author of Radio Resource Management (2001) and Cellular Communications: A Comprehensive and Practical Guide (forthcoming) with Professor Reed.

We have been asked to evaluate the network integration synergies identified by AT&T and T-Mobile USA associated with their proposed merger that will increase network capacity and improve network performance. Our qualitative and quantitative analysis strongly corroborates the conclusions of AT&T and T-Mobile engineers that the proposed transaction will produce very substantial capacity and performance gains from cell-splitting, the elimination of redundant GSM control channels, the creation of larger pools of traffic channels, improved load balancing, and an accelerated shift from less efficient technologies to more efficient technologies. In combination, these mechanisms can be expected to improve capacity, coverage and performance of the combined network relative to the two standalone networks. We further conclude that assertions by other parties that AT&T and T-Mobile could independently duplicate capacity and service quality gains on this scale and in this time frame are unsubstantiated and implausible.

Our analyses and conclusions on these issues are set forth in the White Paper entitled "Analysis of Network Efficiencies Associated with The Proposed Acquisition By AT&T, Inc. of T-Mobile USA, Inc.," which is attached hereto as Exhibit 1. We hereby incorporate this White Paper into this declaration.

VERIFICATION PAGE

I hereby declare under penalty of perjury that the foregoing (including the referenced Exhibit) is true and accurate to the best of my knowledge and belief.

Jeffrey Reed
Jeffrey H. Reed

ndtripathi
Nishith D. Tripathi

Executed on June 6, 2011

REDACTED – FOR PUBLIC INSPECTION

Analysis of Network Efficiencies Associated With The Proposed Acquisition By AT&T, Inc. of T-Mobile USA, Inc.

Jeffrey H. Reed and Nishith D. Tripathi

Abstract

AT&T and T-Mobile USA have identified a number of network integration synergies associated with their proposed merger that will increase network capacity and improve network performance. This white paper provides an independent assessment of each of the categories of expected gains. Our qualitative and quantitative analysis strongly corroborates the conclusions of the AT&T and T-Mobile USA engineers that the proposed transaction will produce very substantial capacity and performance gains from cell-splitting, the elimination of redundant GSM control channels, the creation of larger pools of traffic channels, improved load balancing, and an accelerated shift from less efficient technologies to more efficient technologies. In combination, these mechanisms can be expected to improve capacity, coverage and performance of the combined network relative to the two standalone networks. We further conclude that assertions by other parties that AT&T and T-Mobile USA could independently duplicate capacity and service quality gains on this scale and in this time frame are unsubstantiated and implausible.

Professor Jeffrey H. Reed is the Director of Wireless @ Virginia Tech and the Willis G. Worcester Professor of Electrical and Computer Engineering at Virginia Polytechnic Institute and State University. Wireless @ Virginia Tech is one of the largest and most comprehensive academic wireless research groups in the US. Professor Reed is an author or co-author of over 200 peer-reviewed journal and conference papers and the co-author of three books. Late in 2011 his fourth book will be published by Wiley and IEEE, *Cellular Communications: A Comprehensive and Practical Guide*, with his co-author here, Dr. Nishith Tripathi. This book is based on the classes Professor Reed and Dr. Tripathi teach at their respective organizations. Professor Reed is also the President of Reed Engineering, a wireless engineering consulting firm with which Dr. Tripathi is also affiliated. Professor Reed is a Fellow of the IEEE and past recipient of the College of Engineering Research Award. He has served on the technical advisory boards of many companies and has approximately 30 years of industrial and academic experience. Professor Reed's complete vita is attached.

Dr. Nishith Tripathi is a principal consultant at Award Solutions, a provider of technical consulting and specialized technical training for wireless communications. Dr. Tripathi's students include senior personnel from companies throughout the wireless industry as well as other wireless engineering instructors. Dr. Tripathi specializes in a variety of technologies, including IS-95, CDMA2000, 1xEV-DO, GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, HSPA+, WiMAX, and LTE. He received his doctorate in Electrical and Computer Engineering from Virginia Tech, and he has held several strategic positions in the wireless arena. As Senior Engineer for Nortel Networks, Dr. Tripathi gained direct hands-on experience analyzing and optimizing the performance of CDMA networks, in such areas as capacity, handoff and power control algorithms, supplemental channel management algorithms, and switch antenna diversity. As a Senior Systems Engineer and Product Manager for Huawei Technologies, he worked on the infrastructure design and optimization of CDMA2000, 1xEV-DO, and UMTS radio networks. Dr. Tripathi is the co-author of *Radio Resource Management* (2001) and, with Professor Reed, *Cellular Communications: A Comprehensive and Practical Guide* (forthcoming). Dr. Tripathi's complete vita is attached.

1. Executive Summary

In connection with its proposed acquisition of T-Mobile USA, AT&T's and T-Mobile USA's engineers have identified a number of ways in which combining the two companies' wireless networks and spectrum will produce substantial capacity and service quality gains. As detailed in the April 20, 2011, Declaration of William Hogg, AT&T's Senior Vice President of Network Planning and Engineering, AT&T expects the combination to: (1) enable a denser cell site grid that allows greater re-use of spectrum bandwidth, (2) reduce the amount of spectrum required for GSM control channels, (3) enable larger channel pools that boost capacity by 10-15%, (4) improve spectrum utilization in areas where one company's network is heavily loaded and the other's is lightly loaded, (5) accelerate the shift of spectrum from less to more spectrally efficient technologies, and (6) improve coverage and signal reception, particularly at cell edges and inside buildings. AT&T contends that, in combination, these network synergies will allow the combined company both to improve the quality of the wireless services it provides to its customers and to better meet rapidly rising demand for mobile broadband Internet services.

We have been asked by AT&T to review, from an engineering viewpoint, claims that these network synergies are unlikely to be achieved, are overstated, or could easily be duplicated without a merger.[1] As we explain below, we find that each of the categories of network synergies that AT&T has identified is real and achievable in practice; that the engineering assumptions and logic that AT&T's engineers have employed to demonstrate the synergies are consistent with wireless engineering theory and commercial cellular network practice and experience; and that consumers are, in fact, likely to experience substantial and tangible benefits from network integration and evolution that proceeds as AT&T has described. We further conclude that the claims that AT&T and T-Mobile USA could independently duplicate capacity and service quality gains on this scale and in this time frame are unsubstantiated and implausible.

Each of the network synergies AT&T has identified follows directly from basic principles of radio frequency ("RF") engineering. The capacity and service quality impacts of cell splitting, control channel use, channel pooling, utilization efficiency, and shifts from older, less spectrally efficient to newer, more spectrally efficient technologies are all part of the cellular technology courses we teach to our university and industry students. These effects are well-established in both theory and real world engineering experience. Furthermore, concerns that AT&T has not fully quantified the capacity benefits are misguided because these types of network synergies resist precise quantification. That does not make them any less real or significant.

* * *

The remainder of this white paper is organized as follows:

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[1] These claims appear in the May 28, 2011, Declaration of Steven Stravitz, Chief Executive Officer and Managing Director, Spectrum Management Consulting, which is Attachment G to the Petition to Deny of Sprint Nextel Corporation (Federal Communications Commission WT Docket No. 11-65) ("Stravitz").

In **Section 2**, we provide an overview of the capacity challenges faced by wireless engineers in an environment of rapidly growing and changing uses of wireless networks. We explain how spectrum or capacity "exhaust" occurs in real world wireless networks as the demands on the network exceed available resources in cell site sectors at busy times. Traffic levels vary widely and dynamically among sectors and over time, and what matters to the network planner is the peaks, not the averages. Meeting customers' expectations for blocked and dropped calls and throughput only where and when usage is at or below average is a recipe for customer dissatisfaction. For these reasons, criticisms that AT&T's network efficiency predictions are not quantified in terms of precisely how many more calls the combined network will be able to carry, for example, are misguided. Such estimates are neither meaningful – the answer depends upon the geographic and temporal distribution of the traffic and the service quality levels AT&T and its customers will tolerate – nor subject to precise quantification. Nonetheless, it is well established in both theory and real world network experience that the types of network integration efficiencies that AT&T anticipates are real and substantial.

In **Section 3**, we examine AT&T's cell density analyses and conclusions. We conclude that AT&T's expectation that it will be able to retain and integrate more than **[Begin Confidential Information]** **[End Confidential Information]** T-Mobile USA cell sites, greatly increasing cell density in many areas and effectively doubling capacity in those areas, is reasonable. Mr. Hogg explains that AT&T generally considers urban cell sites that are **[Begin Confidential Information]** **[End Confidential Information]** from existing AT&T sites and rural sites that are **[Begin Confidential Information]** **[End Confidential Information]** from existing AT&T sites to be complementary. In our experience, these are reasonable and, indeed, conservative criteria, and we provide site-specific analysis from a sample market that confirms this. Although AT&T's final cell site retention decisions will undoubtedly reflect site-specific analyses, it is our experience that in areas that are particularly traffic-intensive, good engineering practice may support new cell sites that are closer **[Begin Confidential Information]** **[End Confidential Information]** from existing sites, and the cell density benefits associated with the transaction may therefore be even greater than Mr. Hogg's preliminary analysis suggests.

We also explain why it is wrong to assume that the benefits of immediate access to T-Mobile USA's existing cell sites could be replicated by AT&T on a standalone basis. The old adage about real estate value – "location, location, location" – applies with special force in the wireless cell site context. Whether placed on a tower, rooftop or other structure, the value to a network planner of a new wireless radio/antenna in terms of coverage and capacity is heavily dependent upon location and orientation relative to both existing cell sites and natural and manmade obstructions. Identifying and securing new cell sites at optimal locations has become increasingly difficult in recent years as networks become more mature, thus requiring greater precision for locations, and as acceptable tower, rooftop and other locations have become increasingly occupied. We find no support for, and find implausible, claims that AT&T could use new cell site builds to replicate, on a timely basis, the enormous cell density benefits of replacing T-Mobile USA radios/antennas at more than **[Begin Confidential Information]** **[End Confidential Information]** locations with new multi-band radio/antennas.

In **Section 4**, we examine AT&T's analyses and conclusions regarding GSM control channels. GSM technology utilizes 200 KHz spectrum "channels," some of which are assigned as "control" channels (*e.g.*, for signaling) and some of which are assigned to the "hopping pool" principally used to carry customers' voice and data traffic. As standalone networks, both AT&T and T-Mobile USA must each devote spectrum to GSM control channels. The amount of spectrum allocated to control channels in a particular area is primarily a function of the network "frequency reuse" plan in that area, which itself is a function of many factors, including network configuration and operational philosophy. We understand that AT&T's networks have been designed to support a "tighter" frequency reuse plan that typically requires no more than a total of 4.8 MHz of control channel spectrum, but that T-Mobile USA's network design is different and that T-Mobile USA requires as much as 10 MHz for control channels. We agree that combining the two GSM networks will free up for other uses the spectrum currently employed by T-Mobile USA for control channels. To the extent this spectrum can be shifted to more spectrally efficient UMTS or LTE networks, the capacity gains will be very substantial.

In **Section 5**, we explain and validate the GSM channel pooling efficiencies AT&T has identified. This is an area in which established wireless engineering theory and practice may be counterintuitive – combining even two "full" networks can produce substantial capacity gains. A wireless network employs a "pool" of channels to communicate with user handsets in a given sector. The larger the channel pool, the greater the likelihood that a channel will be available when a user needs it. Doubling the size of the pool more than doubles that statistical likelihood – and thus more than doubles available capacity. Proof of this concept requires use of relatively sophisticated statistics and math. Mr. Hogg has provided a simplified analogy to illustrate the concept; we attempt to build on the analogy below. AT&T estimates that capacity gains of 10-15% are likely to be achieved. Based upon the analysis we have done here and prior to the merger activity, we agree. Indeed, we expect that the realized gains could be at the higher end of this range, and we note that these gains are achievable even where both companies' networks are heavily loaded.

In **Section 6**, we address utilization efficiency gains. We understand that in some areas, AT&T's networks are heavily loaded while T-Mobile USA's are not. This may occur both across and within specific markets. AT&T contends that by combining the two GSM networks in such situations, the combined spectrum will be more efficiently used. We agree. This is particularly true, of course, where combining the two GSM networks frees up spectrum that can be shifted to more spectrally efficient UMTS and LTE networks that can deliver much more traffic-handling capacity with that spectrum. Furthermore, based on our prior research and testing, we expect that an additional "carrier load balancing" gain of 10-15% magnitude is achievable once the UMTS networks are combined (even if both companies' networks are heavily loaded).

Section 7 addresses the efficiencies associated with shifting spectrum from less to more spectrally efficient technologies. AT&T contends that the proposed transaction will facilitate such shifts in several ways. First, by enabling more efficient GSM operation (through the cell splitting, control channel, channel pooling and utilization efficiencies), the combined company can allocate less spectrum to support this less efficient technology than would have been required if the companies continued to operate on a standalone basis. Second, we understand that T-Mobile USA holds AWS spectrum (some of which is currently unused and some of which is currently deployed in T-Mobile USA's UMTS networks) in a number of areas where AT&T has little or no 700 MHz or AWS spectrum available for LTE deployment.

The ability to shift spectrum to more spectrally efficient technologies is among the most important efficiencies associated with the transaction. Although AT&T's continued operation of both older and newer technology networks is a necessary and expected product of the cellular technology lifecycle, the transaction-specific synergies that enable AT&T to accelerate and improve its LTE network build-out and to shift more spectrum sooner from the GSM network to the newer, more efficient UMTS and LTE networks are enormously beneficial. Even in its earliest incarnations, LTE technology can carry many times the amount of traffic as GSM and, to a lesser degree, HSPA+ on a given amount of spectrum. Moreover, LTE has numerous other advantages over HSPA+ including improved latency, scalability, and economies of scale.

Finally, **Section 8** addresses claims that AT&T could readily resolve its capacity and spectrum constraints through better "stewardship" of its existing spectrum and through efforts to deploy more advanced technologies, including heterogeneous micro, pico, femto, and relay cells, WiFi, distributed antenna systems, smart antennas, and software defined radios. As we explain below, these claims rest on fundamental misconceptions of sound engineering practice and ignore the limits of these technologies that AT&T *is* widely deploying, but that can provide only localized capacity relief, and not the broad, large-scale *macro* capacity and performance improvements associated with network integration.

2. Capacity and Network Integration Basics

AT&T and T-Mobile USA have submitted information and declarations indicating that they believe the merger will allow the combined company to achieve many different types of efficiencies and increases in network capacity. Each of these efficiencies arises from taking two standalone networks and using combined facilities and spectrum to create a single combined network that makes better use of the spectrum. In particular, the integration of the two networks is expected to increase network capacity and performance through cell splitting, the elimination of redundant control channels, channel pooling, increases in network utilization efficiency, and the shifting of certain spectrum to newer, more spectrally efficient technologies. As we explain in detail below, we believe the merging parties' expectations that the combined company can achieve these capacity and performance improvements are reasonable and, in some cases, likely understate the potential gains.

It is worth emphasizing at the outset, however, the enormous challenges that wireless engineers and network planners face in today's wireless environment. As the FCC and others have widely acknowledged, traffic on wireless networks today, especially traffic from data services, is increasing rapidly. Wireless network engineers are confronted with constant battles to augment network capacity to meet this demand.

When a network is strained, the network planner must add capacity, typically by adding spectrum or increasing the reuse of existing spectrum (by splitting cells) or both. It is important to understand there is no formula a network engineer can turn to that says, for example, my network capacity in New York this month is one million minutes (of voice traffic) or one million megabytes (of data traffic) and since I expect more than one million minutes next month I need to add spectrum and split cells. Traffic levels can vary dramatically and dynamically among "sectors" (*i.e.*, part of the area covered by a single base station),[2] time periods, and even direction (*i.e.*, as between the "downlink" direction from the network to the user and the "uplink" direction from the user to the network). In this environment, network engineers are most concerned with *peak* loads, not average loads. What matters is having enough capacity *when and where customers need it*, and that is constantly changing and very difficult to predict.

Customers have established expectations about dropped-call rates, download speeds and quality of service, and if customers are experiencing unacceptably low levels of service at times of <u>peak</u> load, the carrier must address those concerns by augmenting capacity. Often that may mean network planners must address performance issues in a particular market by adding spectrum and cell sites long before <u>average</u> daily or monthly usage in that market reaches theoretical capacity levels. If network planners worried only about whether dropped-call and blocked-call rates and throughput were acceptable at *average* loads, network performance would be very poor.

Theoretical capacity is not achieved in the real world given temporal and geographic traffic variations, and limitations of practical hardware. Concepts such as capacity exhaust must be understood in the way that network engineers understand them. As traffic grows in sectors and at times of peak load, the resources available to serve customers in those areas (for example "power" and "codes" in UMTS)[3] will fall short of customer demands and performance in those sectors will drop – the sector will be said to be "failing." If even a relatively small number of sectors are experiencing failures frequently, capacity augmentation is necessary.

What we want to emphasize, then, is that simply looking at theoretical measures (*e.g.*, vendor estimates of the maximum capacity for a given amount of spectrum and technology) is insufficient to determine whether a network is experiencing capacity issues or not. In the real world, a carrier is unlikely to be experiencing levels of traffic that approach the theoretical limits of the spectrum's capacity throughout the geographic area and at all times of the day. Instead,

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[2] A sector is a region covered by a base station using a directional antenna. Typically a sector may cover an area spanning 60 degrees or 120 degrees from the base station (such that the sectors of a base station collectively provide 360 degree coverage). In some technologies, such a sector is referred to as a cell. We will use "sector" and "cell" interchangeably in this paper.

[3] In a UMTS system, two main radio resources for the downlink are transmit power and OVSF (Orthogonal Variable Spreading Factor) codes that distinguish streams of data. The number of OSVF codes available can limit the number of users that can be handled at the cell. Total power transmitted also can limit the number of users since the power has to be divided among all the users in the cell and the more users in the cell, the less power that can be allocated to each user.

engineers determine where and when capacity must be augmented to a large extent based on monitoring of network performance under the loads actually being experienced. If peak loads in even a small number of sectors in a market are straining the system, then good engineering practice mandates capacity augmentation in that market. The key issue is whether the consumer can access the network *reliably* at the busiest times and locations. In short, while theoretical measures may be viewed as performance bounds, real-world effects ensure that actual network capacity, even under the best of conditions, will fall short of these bounds.

For all of these reasons, it is extremely difficult to precisely quantify the practical real world "capacity" of a network at any given place or time in absolute terms, and certainly not across an entire network – that sort of network-wide concept of "capacity" does not tell us anything useful from a network engineering perspective. And for these same reasons, criticisms that AT&T has not *precisely* quantified the increases in capacity it hopes to gain from integrating the two networks are not well founded. Although we can provide a mathematical justification and ranges of likely magnitudes and trends for some of the performance gains we discuss, it is impossible analytically to determine the *exact* gains due to the enormous complexities of real-world wireless networks.

But the fact that these efficiency gains cannot be quantified with great precision does not mean that they are not real. Although *absolute* capacity and throughput are very difficult to estimate, establishing the existence and rough magnitude of *relative* gains due to specific network changes is a more practical exercise, as the same baseline assumptions can be made in the two scenarios to be compared. For these reasons, even though the actual gains from network integration will depend on a number of variables, we can be confident of the relative magnitude and direction of the changes.

3. Cell Splitting

AT&T has indicated that it expects to retain and integrate into its networks more than **[Begin Confidential Information]** **[End Confidential Information]** T-Mobile USA cell sites. These are cell sites located *in between* existing AT&T cell sites, and integrating these complementary cell sites into the existing network grid results in cell splitting – *i.e.*, one larger cell becomes two smaller cells. Because the traffic handling capacity of a cell is not dependent on the size of the cell (*i.e.*, all else being equal, a small cell can handle the same amount of traffic as a large cell),[4] splitting one cell into two can have the effect of doubling traffic handling capacity in the affected area.

This is an example of the principle of frequency reuse, which is a defining characteristic of cellular networks. By using more base stations in the same spectrum band in the same area and by reducing the effective coverage of each of those base stations, the same spectrum frequencies can be "reused" more often.

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[4] Of course, the larger cell will have more geographic coverage than the smaller cell.

For example, at the risk of oversimplification, assume that the voice capacity of a cell (based upon the channel bandwidth) is 60 voice calls,[5] and the cell is capable of sending and receiving calls from within an area of approximately 65 square kilometers. What happens if our target performance metrics require support for 120 simultaneous voice calls? If we deploy just one base station to cover the 65 square kilometer area, a subscriber can make a call anywhere in the cell, but when the total number of voice calls in the cell exceeds the cell capacity (60 voice calls), new call attempts will be blocked. To maintain high quality service, the carrier can "split" the cell in two – it can deploy *two* base stations to meet the traffic demand of 120 voice calls with each cell taking care of 60 voice calls. This example shows that cell-splitting can easily double the network capacity in a given area when one large cell is replaced by two smaller cells, with each cell covering a separate geographic area.

In the real world, however, carriers must overcome many obstacles to increase cell density through cell splitting. Inter-cell interference is one key engineering issue. Within limits, interference is managed by taking advantage of the underlying physics behind electromagnetic radiation, which is that radiated power decreases *exponentially* with distance from the transmitter. And adding a new base station is useful only if it in fact improves capacity and/or coverage and does so without (significantly) interfering with other cells (and reducing capacity, coverage or service quality). This is primarily a matter of location, and depends on finding available new sites that meet stringent requirements concerning location, height, orientation, and lack of obstructions.

When looking for new base station locations, the RF network planner typically uses a geographic "search ring" or search area map that depicts the ideal cell-site location (*e.g.*, the center of the search ring) and the surrounding area. Those optimal locations may not be available, however, for a wide variety of reasons – for example, existing towers at those locations may be full, the property owner may not want to support cell network structures, or there may be manmade or natural obstructions that would interfere with RF propagation. The lack of availability of a cell-site in the ideal location compels the network planner to settle for a suboptimal location or to forgo the cell split. This is particularly true for mature networks that already have numerous base stations in many of the most optimal locations (*i.e.*, the search ring for acceptable candidates keeps getting smaller over time).

Furthermore, our experience is that even in the best of circumstances, cell splitting can be a slow process. Among many other steps, search rings must be established, potential locations must be assessed, occupancy negotiations must take place, permits and zoning approvals (which can take a very long time and can be unpredictable) are typically required; the carrier must secure backhaul communications to support the base station connection to the overall network (which may require the installation of new fiber facilities); land may need to be purchased or leased and

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[5] For the sake of simplicity of this example, we are not differentiating between the maximum number of users and the average number of simultaneous users ("Erlang" capacity), which are related to each other via a performance metric called Call Blocking Probability.

towers constructed or augmented. By integrating existing T-Mobile USA base stations into its network, AT&T can avoid these obstacles.

Side Note: Quantitative Analysis of Cell-Splitting Gain

Let $N_{separate}$ be the capacity of an operator in a particular geographic area and $N_{combined}$ be the area capacity of the combined operator in the same geographic area. Furthermore, assume that $C_{separate}$ is the number of cell-sites for each operator prior to the merger and that $C_{combined}$ is the number of cell-sites for the combined operator. The capacity increase factor for the combined operator, CIF, as a result of "cell-splitting" is given by

$$CIF = \frac{N_{combined}}{N_{separate}} = \frac{C_{combined}}{C_{separate}} \qquad (3.1)$$

If the number of cell-sites doubles in a given geographic area, $(C_{combined}/C_{separate})$ is 2 in Eq. (3.1), doubling the area capacity.

As long as SIR (Signal-to-Interference Ratio) is controlled by suitable network planning to be the same before and after the cell-splitting process, the same error rate (*i.e.*, Quality of Service) would be maintained and capacity is increased. To demonstrate how SIR could be the same before and after cell-splitting, let $SIR_{separate}$ be the SIR before cell-splitting and $SIR_{combined}$ be the SIR after cell-splitting. $SIR_{separate}$ is given by [TripathiReed_CellularBook]

$$SIR_{separate} = \frac{\left({}^{D}/_{R}\right)^{n}}{6} \qquad (3.2)$$

Where R is the cell radius before cell-splitting, D is the co-channel distance (*i.e.*, the distance between the cells that use the same radio frequency channel), and n is the path loss exponent (*e.g.*, 3.5 to 4 in typical cellular environments).

After cell-splitting, $SIR_{combined}$ is given by [TripathiReed_CellularBook]

$$SIR_{combined} = \frac{\left({}^{\left(\frac{D}{2}\right)}/_{\left(\frac{R}{2}\right)} \right)^{n}}{6} = \frac{\left({}^{D}/_{R}\right)^{n}}{6} \; (3.2)$$

In other words, when one cell is split into two cells, both cell radius and co-channel distance decrease by the same amount, resulting in the same SIR before and after cell-splitting. Suitable network optimization would, of course, be needed to reach the theoretical results summarized here. Note that the cell capacity is independent of the cell size. All else being equal, a large cell in a rural environment and a small cell in a dense urban environment have the same capacity. Hence, when we have more cells per given area due to cell-splitting, as shown clearly by Eq. 3.1, overall system capacity is higher.

We agree with AT&T that this integration provides the combined company the flexibility to, in effect, achieve thousands of cell-splits throughout the areas in which the parties' networks overlap, effectively doubling capacity in those areas. In addition, since the RF network planners in the combined company now have access to more candidates from which to choose cell-site locations, the likelihood of an optimal network design increases significantly.

AT&T has stated that its estimate of more than **[Begin Confidential Information]** **[End Confidential Information]** cell site additions is based on assumptions that cell sites are very likely to be complementary when they are at least **[Begin Confidential Information]** **[End Confidential Information]** apart in urban areas and at least **[Begin Confidential Information]** **[End Confidential Information]** apart in rural areas. These assumptions are reasonable and, in our view, are likely conservative. Although AT&T's final cell site retention decisions will undoubtedly reflect site-specific analyses, it is our experience that in areas that are particularly traffic-intensive, good engineering practice may support new cell sites that are closer than **[Begin Confidential Information]** **[End Confidential Information]** – and therefore AT&T may be able to incorporate even more T-Mobile USA cell sites into its network than currently estimated.

Stravitz faults AT&T for failing to provide an actual engineering analysis of each T-Mobile USA cell site to prove the complementary nature of the two cell grids. In our view, it is not reasonable to expect such site-specific engineering work to have been completed at this early stage. Nor does the absence of such analysis call into question the cell-splitting benefits AT&T has identified. As noted, AT&T's distance criteria are conservative. Stravitz (at 50) recognizes this, noting that cell radii as low as 300-400 meters may be beneficial in dense urban areas.

Furthermore, there are sound engineering reasons to expect that a high proportion of the T-Mobile USA sites that meet AT&T's distance criteria are located in high traffic areas where the additional capacity associated with integration will be most beneficial. Much more so than AT&T, T-Mobile USA's network assets are concentrated in urban population centers.[6] T-Mobile USA's cell grid, built to support the PCS and AWS spectrum used in its 2G and 3G/4G networks, is particularly dense in geographic areas such as New York City and San Francisco where AT&T has had widely publicized network performance issues. And it is simply incorrect to imply that T-Mobile USA's cell sites are unlikely to be located in high traffic areas. Like any prudent operator, T-Mobile USA has undoubtedly designed its network to locate base stations, to the greatest extent possible, in traffic "hot spots" – and since T-Mobile USA deployed its 3G/4G network relatively recently compared to AT&T and others, its design decisions could take account of experience with wireless broadband usage patterns.

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[6] T-Mobile USA has advised us, for example that **[Begin Confidential Information]** **[End Confidential Information]** of its mobile wireless subscribers and **[Begin Confidential Information]** **[End Confidential Information]** of its cell sites are located in the 50 highest population CMAs.

Our quantitative analysis confirms this. We asked the parties to the transaction to provide us with the locations (latitude/longitude) of each of the AT&T and T-Mobile USA cell sites in the city of San Francisco as well as sector level peak load data for each sector associated with those cell sites (based upon a metric known as "bouncing busy hour" usage). We then compared the locations of the T-Mobile USA cell sites to the locations of the AT&T sites/sectors in that city that AT&T currently classifies as already experiencing peak overload and sites and sectors that are approaching peak overload.[7] The results of our analysis strongly confirm AT&T's distance-based metric for synergistic gains – a high proportion of the T-Mobile USA cell sites are well-located in and around the sectors that are or will be experiencing congestion. Mr. Hogg performed a similar analysis for San Francisco and Washington, D.C., and the spacing of the heavily loaded AT&T sites relative to the location of the T-Mobile USA sites is depicted on maps attached to his reply declaration.

Stravitz suggests that even if the T-Mobile USA sites are complementary, they are unlikely to provide capacity relief because the T-Mobile USA base stations in those high traffic areas are also likely to be heavily loaded. This assertion is incorrect. Even if *all* of the cell sites in the highest traffic areas are heavily loaded, the integration will still yield very significant capacity and service quality improvements from the increased cell density and the GSM control channel redundancy, channel pooling, and spectrum shifting efficiencies we discuss below. In any event, our examination of T-Mobile USA busy hour traffic data confirms that in the AT&T sectors that are either at or approaching peak overload, the vast majority of nearby T-Mobile USA cell sites are not capacity constrained.

In addition to the obvious capacity gains from cell-splitting, the integration of the two networks' cell sites can provide additional efficiencies in ways that may not be as obvious. For example, two close-by T-Mobile USA and AT&T cell-sites may have different antenna heights. In such a case, the combined company can choose to retain whichever cell-site has a more appropriate antenna height to optimize network performance. Since a change in the antenna height typically triggers a zoning permission, carriers typically discourage modification of the height of an antenna once it is constructed. However, the combined network already has the required zoning permits for the existing antenna heights, and, hence, a more optimal network design is made feasible without any time loss associated with the process of obtaining zoning permits.

Integration can also improve reliability in certain locations. For example, there may be coverage holes in the existing AT&T network and/or the existing T-Mobile USA network due to building blockage that can be addressed by the denser cell grid and additional cell sites made possible through network integration.[8]

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[7] In UMTS-based systems, power (expressed as a percentage of the total downlink High Power Amplifier power) and OVSF codes are the most important radio resources and constrain the achievable capacity and throughput.

[8] In addition, if certain cell-edge areas in T-Mobile USA's GSM or UMTS network have a lower reliability and throughput than desired, subscribers in those areas could benefit from better RF propagation properties of AT&T's 850 MHz band.

In some cases the AT&T and T-Mobile USA coverage areas and infrastructure may be redundant, especially in areas that are not capacity constrained. Even though it may seem counter-intuitive, removal of the redundant infrastructure could lead to capacity increases in *the overall network*. Today, resources are needed to provide coverage in some areas and at least some traffic channels must be reserved for this purpose for both the AT&T and T-Mobile USA networks. In a merged network, a single cell site from the combined network would be sufficient. Since the interference potential from removed traffic channels is gone, the channel planning can be altered to better service nearby areas that are capacity-challenged.

Although some have suggested that AT&T could achieve similar results simply by pursuing construction of new base stations on its own, we find it implausible that AT&T could achieve capacity gains on anything like the scale that could be achieved through the merger in any remotely similar time-frame. In many cases, these locations may not be available to AT&T today for new construction. But even ignoring this problem, the gating factors to new cell site construction that we noted above make it implausible that AT&T could replicate these sites in the 9-24 month period it expects for network integration, especially given that it took T-Mobile USA much longer to construct the network it operates today.[9]

4. Redundant Control Channels

AT&T believes it will be able to achieve capacity gains from the elimination of redundant control channels. We agree that when radio networks of two GSM operators are combined, some overhead channels can be eliminated, making more resources available to carry user traffic – either on the GSM network or on a more spectrally efficient UMTS or LTE network.

In a cellular network, some radio channels are traffic channels used to exchange user traffic, while some radio channels are "overhead" or "control" channels. In GSM, control channels called Broadcast Control Channels (BCCHs) are overhead channels and can consume a significant amount of spectrum. GSM uses 200 kHz-wide radio frequency channels (RFCHs).

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[9] Stravitz provides no support for his claim that "industry averages for new site construction are from six to twelve months," and, in our experience, any established operator confronted with a need to deploy thousands of new sites would consider these rarely attainable "best case" (not average) time frames, particularly in the context of new site construction in heavily populated areas that already support relatively dense cell grids. Stravitz' claim (¶ 45 & n.39) that Clearwire deployed 10,000 cell sites in 2010 is not a useful reference in this context. One has to keep in mind that Clearwire was deploying a brand new network in a "greenfield" situation, and thus would have much greater flexibility in finding complementary cell site locations than a mature carrier like AT&T. In a greenfield deployment, the network planner faced with challenges in locating a site complementary to the locations of neighboring sites can simply shift the locations of the neighboring sites on the drawing board until an optimal design with readily attainable base station locations can be worked out. For AT&T, in contrast, available locations are limited in practice by the search ring defined by the locations of existing base stations.

One of these 200 kHz RFCHs in each cell[10] will be designated as a BCCH carrier, and is separate from the other RFCHs that are used to carry voice and data. The BCCH is a logical channel that carries information for all the users in the cell so that mobile devices are aware of specific network parameters necessary to connect to the cell site. For instance, the BCCH carries base station-specific information such as the configuration of common channels, the number of common control channels, and whether such channels carry certain signaling messages. GSM uses the multiple access technique called time division multiple access, where the same RFCH can be shared among multiple users through time-slots as shown in Figure 4.1. [TripathiReed CellularBook]

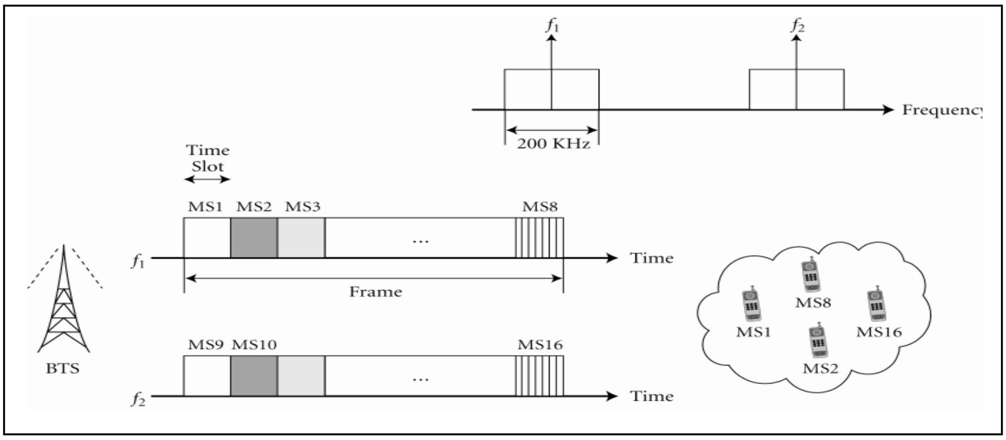

Figure 4.1. Time Division Multiple Access in GSM

The mobile stations in the cell must be able to reliably detect the BCCH carrier frequency in that cell. Hence, different cells in a given neighborhood must use different RFCHs as BCCH carriers. The amount of spectrum devoted to these control channels is a function of the "frequency reuse factor." For example, an operator may use clusters of 21 cells, where each cell (*i.e.*, 120° sector) is using a different BCCH carrier frequency; that operator's BCCH frequency reuse factor would be 1/21. Another operator may use clusters of twelve cells, in which each of the twelve cells is using a different BCCH carrier frequency; that operator's BCCH frequency reuse factor would be 1/12. These differing factors reflect certain trade-offs: a larger cluster size increases the reliability of the BCCH detection, but it requires more RFCHs in each cluster (and thus uses more spectrum).

When two independent operators are covering a given geographic area, each operator needs to reserve a set of BCCH carriers. Different operators may have different network design, network operation, and network optimization philosophies for the frequency reuse of the BCCH carriers. Some operators may have smaller cluster sizes and some may have larger cluster sizes for the BCCH carriers. Furthermore, a given operator may use different strategies for the BCCH frequency reuse in a given geographic area depending upon operator-specific factors such as BCCH detection reliability targets, the homogeneity of antenna heights and available spectrum.

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[10] The term "cell" here refers to the 120° sectorized region.

When GSM radio networks of two operators are combined, however, two different BCCH sets are no longer needed; one BCCH set is adequate. We therefore agree that the merger of AT&T and T-Mobile USA will permit the elimination of redundant BCCH carriers in this fashion. Furthermore, our understanding is that AT&T's network employs a relatively "tight" frequency reuse plan (small clusters) that typically enables AT&T to devote only 4.8 MHz of spectrum for control channels, whereas T-Mobile USA employs a relatively "loose" frequency reuse plan (larger clusters) in some areas that often will devote more spectrum, sometimes as much as 10 MHz, for control channels. For this reason, the merger's elimination of redundant control channels should free up significant spectrum, in many cases enough to permit immediate redeployment of that spectrum for UMTS.

Table 4.1 summarizes the savings expected to result from the elimination of the redundant BCCH carriers for various BCCH frequency reuse factors. The table was created by computing the downlink spectrum released by elimination of the redundant BCCHs, which is given by

$$B_{DL} = N\, f_{DL}, \qquad (4.1)$$

where f_{DL} is the bandwidth of one RFCH, which is 200 kHz and N is the cluster size such that (1/N) is the frequency reuse factor for the BCCHs. The total spectrum released in the downlink and the uplink due to the removal of redundant BCCH removal is

$$B_{total} = 2\, B_{DL}, \qquad (4.2)$$

Table 4.1. BCCH Frequency Reuse and Associated Spectrum Available for UMTS

BCCH Frequency Reuse	Spectrum Bandwidth Occupied by BCCHs in the DL	Spectrum Bandwidth Available for UMTS After BCCH Elimination		
		Downlink	Uplink	Combined Downlink and Uplink
12	2.4 MHz	2.4 MHz	2.4 MHz	4.8 MHz
18	3.6 MHz	3.6 MHz	3.6 MHz	7.2 MHz
21	4.2 MHz	4.2 MHz	4.2 MHz	8.4 MHz
24	4.8 MHz	4.8 MHz	4.8 MHz	9.6 MHz
25	5.0 MHz	5.0 MHz	5.0 MHz	10.0 MHz

Elimination of the BCCHs frees up both uplink and downlink spectrum. GSM uses the BCCH carrier frequency for the BCCH in the downlink, while an associated carrier frequency in the uplink is used to carry uplink channels such as the random access channel. Mobile devices use the random access channel to contact the radio network when they do not have any dedicated radio resources assigned to them by the radio network – for instance when a phone contacts the network to initiate a call. The downlink frequency channel and the uplink frequency channel are separated by a specific spacing in GSM (*e.g.,* 45 MHz). Hence, when the BCCH carrier frequency is freed up in the downlink, the related RFCH in the uplink also becomes available.[11]

Although Stravitz does not disagree that integrating the two GSM networks will allow AT&T to repurpose the spectrum that T-Mobile USA currently allocates to control channels, he questions the amount of spectrum that would be freed up in this manner and AT&T's ability to manage the frequency planning that would be needed to repurpose the former control channel spectrum for UMTS. Stravitz ¶ 35. Neither concern is well founded. As we explain above, the number of 200 KHz channels allocated as control channels (and hence the total amount of control channel spectrum) is a straightforward function of the frequency reuse plan. We have reviewed the T-Mobile USA frequency reuse plans and concur in AT&T's determination that the redundant control channels represent 4.8 to 10 MHz (varying due to the frequency reuse plan variations among markets). And while Stravitz is correct that repurposing the spectrum will require some frequency planning, that is standard fare for commercial wireless network engineers who are constantly shifting spectrum as cellular technology cycles evolve and should present no serious obstacles to the spectrum migration AT&T describes.

Finally, it is not correct to assume that T-Mobile USA could free up spectrum for itself by making its frequency reuse plan "tighter." As we explained, frequency reuse plans often reflect

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[11] While we have only considered the BCCH overhead here, another necessary overhead is the reserved resources for handoff. To reduce the handoff blocking probability to a level much below the new call blocking probability, some resources need to be reserved for handoff users. When two operators' networks are combined, fewer resources would likely be needed for handoff users compared to the case of two independent operators. Resource reduction in handoff resources is another type of overhead reduction that can benefit the combined network.

operator-specific characteristics of the network such as network planning and design and relative antenna heights. Integrating T-Mobile USA cell sites into the AT&T network allows the RF designer flexibility to use the combined network's sites in the most optimal way, whereas it is not necessarily the case that T-Mobile USA by itself could change the architectural and topographical features of its own network in ways that would permit a significant change in the frequency reuse plan.

5. Channel Pooling

AT&T believes that combining the AT&T and T-Mobile USA networks would provide yet additional capacity gains through "channel pooling." We agree that the merger would achieve significant capacity gains through channel pooling – even where both the AT&T and T-Mobile USA networks are "full" to capacity (*i.e.,* can handle no more traffic without jeopardizing target performance levels).

These gains arise from the fact that a wireless network uses a "pool" of channels to communicate with user handsets in a sector in a TDMA/FDMA (Time Division Multiple Access/ Frequency Division Multiple Access) system. If the pool of channels is doubled, as a statistical matter the likelihood that a channel will be available when a user needs it *more than doubles* (holding service quality constant) – meaning that the capacity in that cell in effect more than doubles. In this section, we provide both a mathematical and an intuitive explanation for this statistical phenomenon. The complexity of the radio environment makes precise calculations infeasible, but our analysis does account for real trends and tradeoffs that carriers use to guide deployment strategy, reflects standard design practice, and confirms that that the combined company can expect to achieve significant additional capacity gains from channel pooling.

5.1. Theoretical Foundation of Erlang-B Formulation

We assume that during a busy hour, a hypothetical subscriber may make a certain number of calls with each call lasting for some duration. When multiple subscribers start making calls and begin using the resources of the cell, they generate ("offer") a certain amount of voice traffic. In practice, the number of users starting to make a call and the duration of the call are random variables, and thus at any one instance there may be more or fewer users than average. The "Erlang capacity" is the *average* number of active subscribers in a cell – in other words, an Erlang capacity of 18 means that the average number of simultaneously active calls in a cell (so-called "circuits") is 18.

There is a significant difference between the *cell capacity* and the *Erlang capacity* of the cell. Cell capacity specifies the maximum number of users that can be simultaneously supported in the cell when all the radio resources are fully utilized. For example, if the cell capacity is 25, a maximum of 25 users can simultaneously communicate with the cell, and these users would consume all the radio resources of the cell. If a 26th user attempts to make a call, the radio network will block this call because it does not have any more radio resources to support this call. Since the 26th user will always be blocked, the call blocking probability will be 1 (or 100%)

when 25 users are active in the cell. In the real world, however, network operators do not design their networks to operate so tightly (*i.e.*, at maximum cell capacity), as it would mean that a new user attempting to access the cell would be blocked and users would have a negative perception of the operator's service quality. Instead, cellular networks are usually operated at a call blocking probability of 1% to 3%. [TripathiReed_CellularBook] [BlockingProbability1] [Irnich]. Network operators use the Erlang-B formulation – which is the relationship among three parameters, the cell capacity (also called the number of trunked channels), the call blocking probability, and the Erlang capacity (the "offered" traffic intensity) – to engineer the network properly. An Erlang-B equation or graph can be used to find the third parameter when the other two parameters are known.

Figure 5.1 illustrates the Erlang-B relationship among these three parameters. We have plotted curves for three different values of the call blocking probability – 1%, 2%, and 3%. Thus, for example, when the call blocking probability is 2%, the cell capacity of 40 supports the Erlang capacity of 31.95 Erlang. The critical point, however, is that, for a given call blocking probability such as 2%, the relationship between the cell capacity and the Erlang capacity is *not linear*. As the graph shows, when cell capacity is 15, the Erlang capacity is 9.0 at a call blocking probability of 2%. But if we triple the cell capacity to 45, the Erlang capacity *more than triples* – it rises to 35.60 at the same call blocking probability of 2%. In other words, the Erlang capacity comes closer to the cell capacity as the number of trunked channels increases, which means that relatively more users can be active on average. It is therefore a mathematical fact that a larger pool of trunked channels will yield very significant additional capacity increases due to this "nonlinear" nature of the Erlang-B formulation.

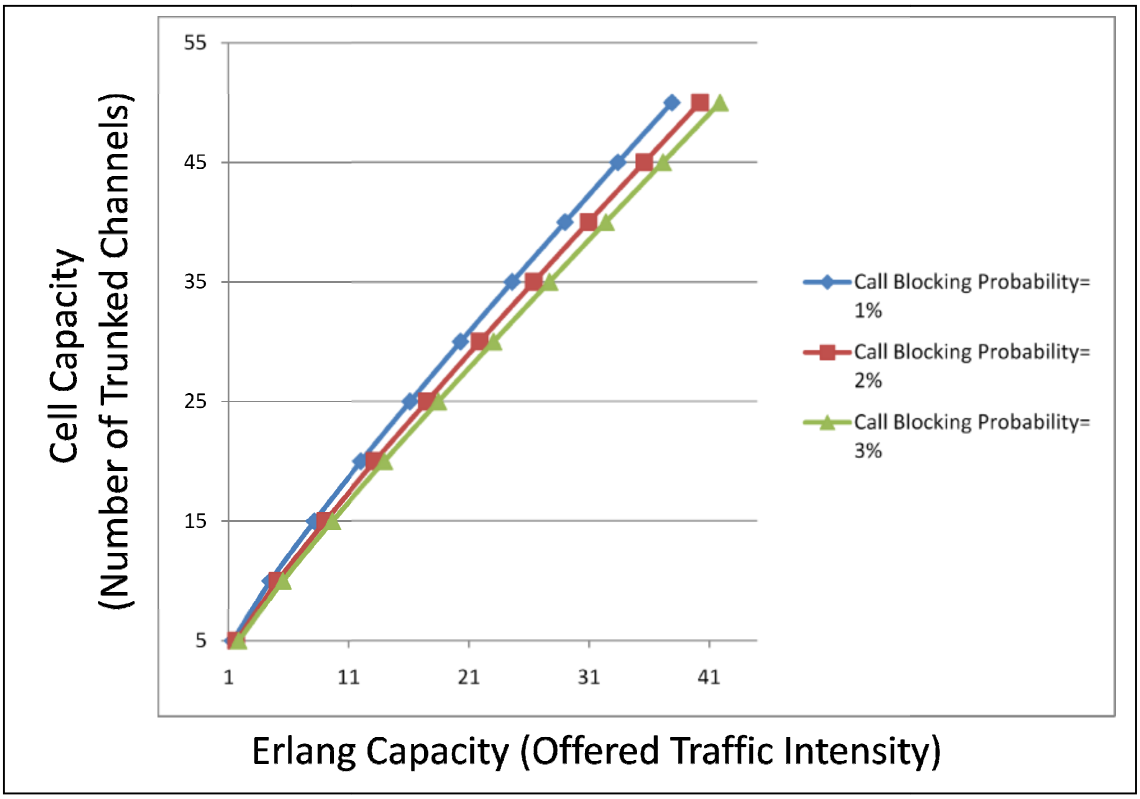

Figure 5.1. Erlang-B Graph Representing Relationship among Cell Capacity, Erlang Capacity, and Call Blocking Probability

5.2 Intuitive Understanding: Analogy to Grocery Store

To understand how doubling the spectrum for a single service provider can result in more than doubling of capacity, let's consider a similar problem: "How many cashiers in a grocery store should be employed so that it is highly unlikely that a customer will need to wait in line?" In this analogy the grocery store check-out stations are like traffic channels in a cellular network. The speed of the check-out process is equivalent to data throughput in a cellular network. The number of people who can be simultaneously checked-out is equivalent to the number of users that can be simultaneously supported by a base station.

Obviously, it is infeasible to have a grocery store that could guarantee that no one would ever have to wait in line. However, if waiting in line became extremely infrequent, the store might advertise a policy of "fast checkout." Wireless service providers have a similar situation, because it would be infeasible to set up a network to guarantee that no one would ever be denied service. The cellular technology equivalent of "fast checkout" is network reliability measured by the relative frequency of "blocked" calls (or "blocking probability").

Let us assume that our hypothetical grocery store is handling maximum capacity in its check-out counters, and it decides to acquire the grocery store next door, which shares a removable wall with our store. Let's also assume that the second store has the same amount of check-out counters, but that its check-out lanes are also maxed out – the second store has the same average number of customers, it has a similar fast checkout policy for its customers, and it too is worried about its ability to serve new customers. Would combining the two stores, both of which are struggling to meet their fast checkout policy, increase the combined stores' capacity to move customers efficiently through its check-out counters? The answer is *yes*. Here's why.

It is rare for both stores to be operating at their maximum capacity, or beyond their maximum capacity, *at the same time*. The number of people coming into the stores is random. Activity levels could follow a trend, such that one store might have better access in the evening or morning due to automotive traffic, it could be the demographic appeal of the store, or perhaps unique items that each store might offer. More likely the variation is the result of a random process that cannot easily be quantified. So, after the merger there may be times that the checkers at the second store are handling the customers that normally go with the first store and vice versa. But the probability of the maximum number of patrons from both sets of stores showing up at the same time is small enough that the merged store can seek even more new patrons and still have the fast checkout policy.

For the same basic reasons, the merger of two wireless service providers with complementary spectrum and technology can provide more capacity than the sum of two service providers operating independently and near capacity, for a given blocking probability. The odds that they would get maximum traffic simultaneously from their respective customer bases are much less than either service provider operating alone. Different customer demographics, coverage area of base stations, services provided, and many other reasons would keep this coincidence from occurring very often. Thus the combined company could accommodate more customers without sacrificing their blocking probability service policy.

5.3 Quantifying Trunking or Pooling Efficiency

The Erlang-B formulation can be applied to estimate the capacity gains that can be achieved by merging the spectrum resources of two wireless operators. When the radio resources of two operators are combined for a given frequency band, the overall pool of radio frequency channels (RFCHs) becomes larger.

Assume for simplicity that both operators have the same number of GSM radio frequency channels. Hence, the total number of RFCHs doubles when these GSM networks are merged. The base station has multiple TRX (transceiver) components. One TRX transmits and receives one RFCH during a given time period such as a TDMA frame. Table 5.1 summarizes the Erlang capacity gain for different numbers of TRXs when the target call blocking probability is 2%.

Table 5.1 Erlang Capacity Gain for the Combined Networks due to Trunking or Pooling Efficiency

Number of TRXs per Operator	Number of Trunked Channels per Operator	Erlang Capacity per Operator	Erlang Capacity for the Combined Operator Without Trunking Efficiency	Number of Trunked Channels for the Combined Operator	Achievable Erlang Capacity for the Combined Operator	Erlang Capacity Gain (= Trunking Efficiency Gain) for the Combined Operator
1	12.8 (13)	7.40	14.8	25.6 (26)	18.35	24%
2	25.6 (26)	18.35	36.7	51.2 (51)	41.15	12%
3	38.4 (38)	29.15	58.3	76.8 (77)	65.8	12%
4	51.2 (51)	41.15	82.3	102.4 (102)	89.9	9%

Consider the case of 2 TRXs per operator. Assume the voice capacity of each TRX is 12.8.[12] For the call blocking probability of 2%, the Erlang-B formulation yields an Erlang capacity of 7.4. When the two operators' networks are merged, one may (erroneously) think that the Erlang capacity available in the cell would be twice the Erlang capacity of a single operator. In reality, however, the achievable Erlang capacity is greater. The number of trunked channels for the

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[12] When full rate speech is used, eight users can share the same RFCH. In contrast, when half rate speech is used, sixteen users can share the same RFCH. The benefit of full rate speech is better voice quality, while the benefit of half-rate speech is higher voice capacity. In a typical commercial environment, 60% of users could be using half-rate speech, and the rest of users would be using full-rate speech. Hence, the number of users supported by one RFCH would be: 40% of 8 + 60% of 16 = 0.4*8 + 0.6*16 = 12.8.

combined network increases to 25.6, and the Erlang-B formulation gives an Erlang capacity of 18.35 Erlang for a call blocking probability of 2% when the number of trunked channels is 26. Hence, when the two networks are combined, they can achieve an additional 24% gain beyond the double capacity. When the number of TRXs per operator is 2 or 3, we have an additional gain of 12%, and in the case of 4 TRXs per operator, an additional 9% gain is achievable. As we explained above, these types of calculations cannot predict the precise gains that can be achieved in the real world because wireless networks are so complex, but these calculations are accurate in their general magnitude and direction. Since the average number of TRXs depends upon the traffic generated by subscribers in a specific area, AT&T's calculations that it can achieve an additional 10-15 percent in capacity gains from channel pooling are entirely reasonable based on our analysis summarized in Table 5.1.

Stravitz claims that these channel pooling efficiencies will not address AT&T's capacity issues, because AT&T's capacity issues are driven by data services, whereas the benefits from channel pooling will be realized only for voice services, will occur only on AT&T's GSM network, and will be "modest."[13] This criticism misses the mark in several ways. First, because the older GSM networks are used predominantly for voice services, GSM channel pooling gains in the range AT&T has estimated would be expected even if such gains were applicable only to voice. Second, it is not the case that channel pooling benefits are limited to voice. The channel pooling benefits apply to *both* the voice *and* EDGE data components of AT&T's 2G network (both of which employ Time Division Multiple Access, or TDMA, technology). That is, integrating the GSM networks will allow the combined network to support more voice users and more EDGE data users at a given data rate than the two standalone networks could serve.[14]

Third, although the capacity gains associated with channel pooling occur in the 2G GSM network, Stravitz misses the point in stating that "AT&T is claiming to get efficiency gains from the older 2G network; it should have focused on upgrading its technology and device portfolio sooner." But that is exactly what the channel pooling and other network integration efficiencies accomplish – by making better use of the spectrum allocated to GSM, they free up GSM spectrum and thus enable the combined company to accelerate the shifting of spectrum to newer, more spectrally efficient technologies. Finally, we would not characterize capacity gains of 10-15% as "modest;" by network engineering standards, these are quite substantial gains.

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[13] Stravitz ¶ 33.

[14] Although, as Stravitz notes, the precise throughput gain due to EDGE channel pooling is very difficult to quantify, a simplified analysis demonstrates that throughput gains are likely to be proportional to the channel pooling gains in terms of supported users. Assume that the average cell throughput is X kbps for an operator when the number of users in the cell is Y. The total cell throughput for two independent networks would be 2X kbps when the number of users is 2Y. However, in the case of the combined network with a 10% channel pooling efficiency, 10% more users are supported, making the supportable number of users (1.10*2Y) = 2.2Y. If 2Y users lead to cell throughput of 2X kbps, 2.2Y users would lead to cell throughput of (2.2Y/2Y) * (2X kbps) = 2.2 X kbps, implying a throughput gain due to channel pooling of (2.2Xkbps/2X kbps)*100% = 10%.

Side Note: A Brief Overview of Erlang-B Formulation

For those readers who like math, the Erlang-B capacity formula assumes that call attempts arrive following a Poisson process – *i.e.,* the arrival times are independent. It is further assumed that message length is exponentially distributed and can be modeled as a Markov process. Eq. (5.1) specifies the Erlang-B formula that is the foundation for Figure 5.1.

$$P_b = \frac{\left(\frac{E^N}{N!}\right)}{\left(\sum_{i=0}^{N} \frac{E^i}{i!}\right)} \qquad (5.1)$$

In Eq. (5.1), P_b is the call blocking probability, N is the cell or sector capacity (i.e., the number of trunked channels), and E is the Erlang capacity. When two of the three parameters (i.e., P_b, N, and E) are known, the third unknown parameter can be found. Numerical issues can make this equation difficult to solve, but tables have been pre-computed to make the analysis easier. Eq. (5.1) assumes a Poisson distribution for the call arrivals. Let λ be the expected number of calls in a given interval T. The probability that there are exactly k calls (with k= 0, 1, 2,…) in the given interval T follows the Poisson distribution that is characterized by [Poisson]

$$f(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}. \qquad (5.2)$$

The call duration is assumed to adhere to the exponential distribution by the Erlang-B formulation. The exponential distribution is expressed by [Exponential]

$$f(x;\gamma) = \begin{cases} \gamma e^{-\gamma x}, x \geq 0 \\ 0, x < 0 \end{cases}, \qquad (5.3)$$

where γ is the call duration.

6. Network Utilization Efficiency

AT&T believes it can achieve other network capacity gains by using the combined company's spectrum resources more efficiently. We agree that the merger will permit the combined company to improve network utilization efficiency,[15] and that is particularly true when the integration allows spectrum to be freed up for more spectrally efficient services using UMTS or LTE. We will consider two scenarios below: (i) Scenario I (applicable to GSM or UMTS networks), where subscriber densities for two operators are different, resulting in significantly different loading[16] of the two networks, and (ii) Scenario II (applicable to UMTS networks) where both networks are reasonably loaded due to high subscriber densities for both operators.

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[15] Network utilization efficiency quantifies the extent to which the available network resources are being utilized. As an example, if the average number of radio resources (*e.g.*, time slots and frequency channels in case of GSM and codes in case of UMTS) used during a time interval is X and the total number of resources is Y, the utilization efficiency for such resource is (100*X/Y).

[16] Loading can be quantified by a variety of metrics in different technologies. One way to define loading is the ratio of the actual number of users in the cell to the maximum number of supportable users in the

6.1. Scenario I: Different Loading Levels due to Different Subscriber Densities

A wireless operator serving a geographic area needs to provide contiguous coverage irrespective of whether there are just a few or numerous subscribers in the service area. When the operator has few subscribers in an area, the network loading in the cells in that area is light. Since the network resources are not being utilized very much due to light loading, the network utilization efficiency is low. Where there is a disparity in the network loading levels of two networks in a given area, their combination may produce utilization efficiencies by balancing the subscriber loading across the resources of the combined network.

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cell. Hence, if the actual number of users is 30 and the cell capacity is 60, we have loading of (30/60=0.5) or 50%. In a CDMA-based system such as UMTS, downlink loading can be measured as the ratio of the actual downlink power transmitted in the cell to the maximum downlink power available in the cell. If the maximum transmit power for a cell is 40 Watts but only 28 Watts power is being transmitted in the downlink to support the currently active users, the downlink loading is (28 Watts/40 Watts= 0.7) or 70%. In the case of LTE, if the average number of physical resource blocks being used is 40 in the case of 10 MHz downlink bandwidth, the loading is (40/50) or 80%. There are 50 physical resource blocks in the 10 MHz bandwidth in LTE.

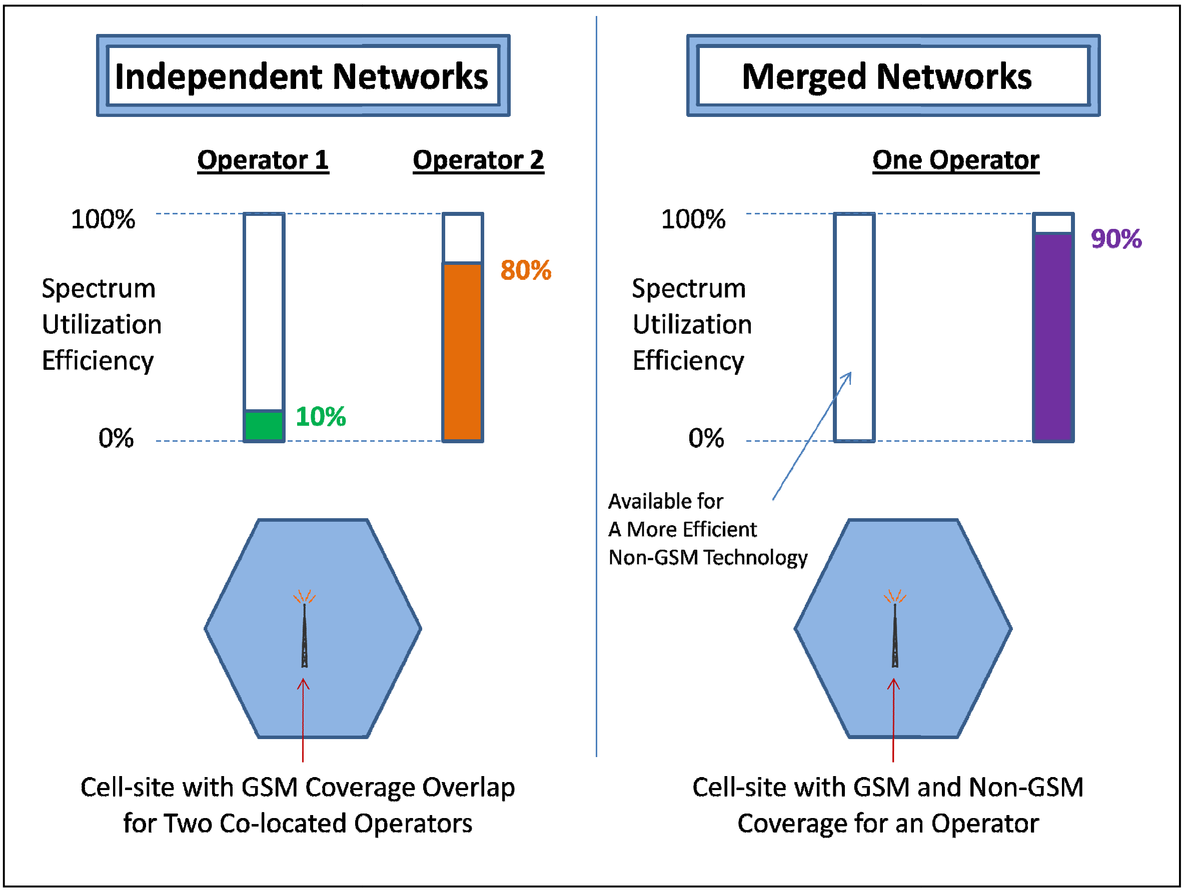

Figure 6.1: Enhancing Network Utilization Efficiency in Case of Vastly Different Subscriber Densities

As Figure 6.1 illustrates, the subscribers from a lightly-loaded GSM network can be moved to a heavily-loaded GSM network, increasing the network utilization efficiency (*e.g.*, from 80% to 90%) of the heavily-loaded GSM network. The now-empty GSM spectrum can be used for a more efficient technology such as UMTS or LTE. Observe that we have not only increased the spectrum utilization efficiency of a GSM network, but we have substantially improved the capacity and spectral efficiency achievable at the cell-site by shifting spectrum to a more efficient non-GSM technology.

Table 6.1 summarizes the expected network and user benefits for various cases when resources from two networks are combined. For the purpose of illustration, we have three levels of loading – light, medium, and heavy. A heavy loading level implies the network running close to its capacity, while a light loading level implies the network operating much below its capacity. A medium degree of loading level, as the name suggests, is somewhere between the light and heavy loading levels. Since each of the operators may have one of the three loading levels at a given instant in a particular area, there are (3*3=9) possible combinations of loading levels. All these combination levels are addressed in Table 6.1. Assume that Operator 1 is using one frequency block (*e.g.*, a block at 1900 MHz in the case of T-Mobile USA), while Operator 2 is using another frequency block (*e.g.*, a block at 850 MHz or 1900 MHz in the case of AT&T).

While there are nine combinations of loading levels for two operators, there are two main outcomes. *One outcome* is what we just described: one frequency block is adequate for GSM, leaving another frequency block for a more efficient technology. The *other outcome* is that the larger pool of GSM channels yields channel pooling/trunking benefits. When the GSM usage declines to a sufficiently low level (as time passes), this second outcome morphs into the first outcome. In case of the first outcome, GSM users continue to receive target Grade of Service (GoS), while the UMTS users enjoy enhanced service experience due to new UMTS spectrum that is now available for UMTS. These UMTS users would see benefits such as better data throughput, fewer call blocks, and seamless and more reliable mobility due to soft handover. In the case of the second outcome, a larger pool of trunked channels yields benefits explained in Section 5. The availability of more radio channels would decrease call blocks and increase EDGE data throughput. Furthermore, when more traffic channels are part of the hopping set, frequency diversity gain and a lower amount of average interference on a channel would improve the reliability of the communications (*e.g.*, lower error rate).

Table 6.1. Expected Network and Subscriber Benefits Under Different Loading Levels

Case	Operator 1 Loading (GSM)	Operator 2 Loading (GSM)	Potential Optimization Strategy	Expected Benefits to the Combined Network	Expected Benefits to the Subscriber
1	Heavy	Light	Use one frequency block for all GSM subscribers and free up the second frequency block for UMTS or LTE	Higher utilization efficiency on a GSM block and much higher spectral efficiency on a non-GSM block	Better throughput, fewer call drops, fewer call blocks, and seamless mobility due to access to a more efficient UMTS or LTE network
2	Heavy	Medium	Exploit trunking by creating a larger pool of GSM channels. Wait for GSM network use to decline to a level that enables a single frequency block to serve GSM users.	Higher GSM capacity.	Fewer call blocks, fewer call drops, improved EDGE data throughput, increased reliability due to (i) potentially higher frequency diversity and (ii) lower average interference resulting from larger frequency hopping set at a given frequency band
3	Heavy	Heavy			
4	Medium	Light	Use one frequency block for all GSM subscribers and free up the second frequency block for UMTS or LTE	Higher utilization efficiency on a GSM block and much higher spectral efficiency on a non-GSM block	Better throughput, fewer call drops, fewer call blocks, and seamless mobility due to access to a more efficient UMTS or LTE network
5	Medium	Medium	Exploit trunking by creating a larger pool of GSM channels. Wait for GSM network use to decline to a level that enables a single frequency block to serve GSM users.	Higher GSM capacity.	Fewer call blocks, fewer call drops, improved EDGE data throughput, increased reliability due to (i) potentially higher frequency diversity and (ii) lower average interference resulting from larger frequency hopping set at a given frequency band
6	Medium	Heavy			
7	Light	Light	Use one frequency block for all GSM subscribers and free up the second frequency block for UMTS or LTE	Higher utilization efficiency on a GSM block and much higher spectral efficiency on a non-GSM block	Better throughput, fewer call drops, fewer call blocks, and seamless mobility due to access to a more efficient UMTS or LTE network
8	Light	Medium			
9	Light	Heavy			

Table 6.1 highlights the complex and dynamic nature of cellular networks. Analysis of network performance is continually carried out once the commercial network is launched. The specific case (out of the nine cases above) could differ from one geographic area to another (*e.g.*, scenarios 1, 3, 5, and 9 could all apply in different areas of the same city).

Although he does not dispute the existence of utilization efficiencies, Stravitz discounts their significance, noting that AT&T has, to date, identified only a few markets where one network is lightly loaded and the other is heavily loaded. As we have explained, however, network integration will yield significant capacity and performance benefits under *any* of the possible loading scenarios. Even if average loading would be characterized as high for both networks in a given market, there will still likely be significant variations in their relative loading levels in particular sectors within the market. And, as we explain below, intercarrier load balancing for UMTS would also increase capacity and throughput. Stravitz fails to appreciate the widespread benefits that could be expected in all markets from load balancing across the entire market. The combined network in a given geographic area would ALWAYS produce pooling and load balancing benefits even under heavy loading levels.

Stravitz also claims that the utilization efficiencies in these scenarios would necessarily result in degraded service for the lightly loaded network's subscribers. There is no engineering basis for this assertion. Networks are designed to ensure a good user experience when the network is operating near its target "full-loading," which implies running the network at the target GoS (Grade of Service) of 1% to 3% call blocking probability and target quality of service (*e.g.*, a certain error rate for a given data rate). Consider an example. During a lightly loaded time period, a network might experience a call blocking rate of 0.05% (*i.e.*, 1 out of 2000 calls), but when traffic demands are high, the call blocking rate might reach the design target of 2% (*i.e.*, 2 out of 100). The users in the latter scenario are not experiencing "degraded" service; rather, they are experiencing the target performance rate, and no commercial wireless operator promises better than target performance at any particular time or place. It is highly improbable that a user would notice the difference between a 2% and 0.05% call blocking rate. What is clear, however, is that the result of the integration of the AT&T and T-Mobile USA networks is increased capacity and increased flexibility for the combined network operator to optimize capacity, service quality and coverage.

6.2. Scenario II: Heavily-loaded Networks due to High Subscriber Densities

Even when two networks are heavily-loaded, significant benefits can be realized by balancing the load evenly across carrier frequencies. We will use the example of a call admission control algorithm to explain the benefits of a combined network in case of heavy loading. When a user makes a call or initiates a data session, the radio network executes a call admission control algorithm that evaluates the availability of radio resources to handle the call. In the case of CDMA-based systems such as UMTS and 1x, the most important radio resources for the downlink are codes and power. A call is blocked if the loading on the available carrier frequency (*e.g.*, percentage of the maximum downlink transmit power) is greater than a call blocking threshold; otherwise, the call is admitted. Figure 6.2 illustrates the benefit of inter-carrier load balancing for a combined network.

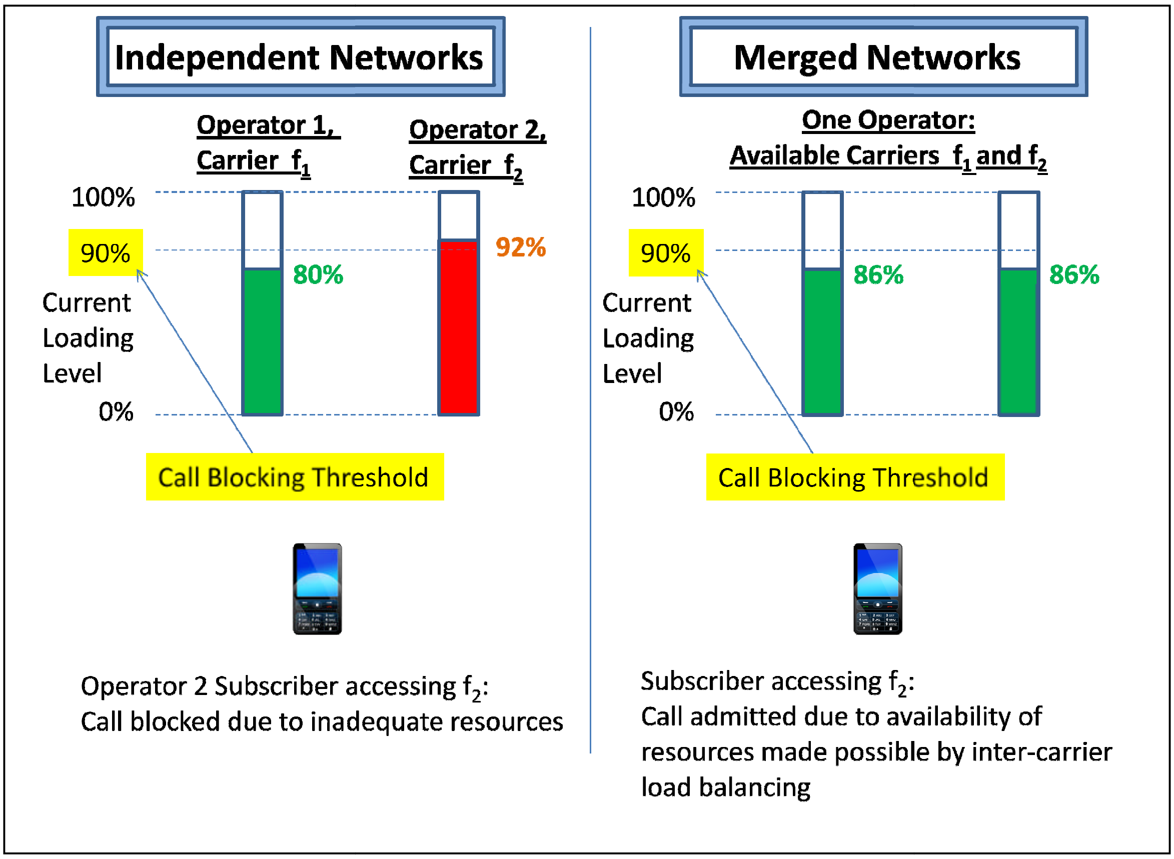

Figure 6.2: Load Balancing in Case of Heavily-Loaded Networks

Assume that two independent networks such as CDMA-based UMTS networks are heavily loaded. Operator 1 has deployed UMTS on carrier frequency f_1 and Operator 2's UMTS network operates on carrier frequency f_2. The average loading level is 80% and 92% for Operator 1 and Operator 2, respectively. When a subscriber attempts to access Operator 2's UMTS network, this subscriber's call is blocked because the average loading of 92% exceeds the call blocking threshold of 90%.

Let's consider the case of a combined network, where the operator has two UMTS carrier frequencies f_1 and f_2. An inter-carrier load balancing algorithm works in conjunction with the call admission control algorithm to balance the load on multiple carrier frequencies. Hence, the average loading on both carrier frequencies is 86% (*i.e.*, (80% + 92%)/2= 86%). When a new call arrives on f_2 (or, f_1), the call is admitted since the average loading is below the call blocking threshold of 90%.[17] The likelihood of a call being blocked decreases due to the operation of the inter-carrier load balancing algorithm when two or more carrier frequencies are available in a given area. The overall system capacity increases for a given target call blocking probability due

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[17] The average loading is the relevant metric because call blocking is related to both the average number of users and the number of channels.

to load balancing and one would expect the average loading for both to go beyond 86% given that calls previously blocked can now be processed by the system.

The radio environment in a cellular system is dynamic. Even when the same numbers of users generating a given amount of traffic exist on two carrier frequencies, the loading levels on two carrier frequencies can be significantly different due to user locations, interference levels, and propagation channel conditions. Furthermore, when some subscribers use data services (*e.g.*, e-mail and video streaming), loading levels on carrier frequencies of two independent networks can be significantly different. Part of this difference, especially for UMTS systems, is that one site might require less overall transmit power to serve users. The combined network offers an opportunity to balance the load across multiple carrier frequencies through an intelligent load-balancing algorithm. CDMA-based commercial 1x and UMTS networks implement such inter-carrier load balancing algorithms.

Research (and experience with commercial networks) indicates that there could be more than a 10% gain in voice capacity due to inter-carrier load balancing in the case of 2 carrier frequencies and more than a 15% gain in voice capacity in the case of 3 carrier frequencies [TripathiSharma_LoadBalancing]. This is a conservative estimate; the load balancing gains can be expected to be higher due to larger variations in loading levels caused by data activity occurring in bursts, and thus spectrum capacity gains may be even greater than anticipated. A more complex call admission control algorithm could match voice and data traffic requirements to the relative strengths of available technologies and carrier frequencies (*e.g.*, UMTS for voice and LTE for high-definition video streaming).[18]

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[18] We would also note that, when two operators' networks are combined, they can also achieve a non-spectrum efficiency benefit in the form of reduced backhaul costs. Assume that the average throughput on each operator's backhaul circuit is 50 Mbps and we have 250 users supported by the cell-site. To provide a certain quality of service, the operators would need to do some amount of over-provisioning. The backhaul bandwidth to be provisioned would be the average throughput multiplied by an effective bandwidth factor. When there are 250 users, the backhaul needs to be provisioned with the effective bandwidth factor of 2.1 to meet a certain target quality of service [BackhaulEfficiency] [Norros1] [Norros2]. Hence, when average throughput is 50 Mbps, each operator would need to provision (50 Mbps *2.1 = 105 Mbps). Two independent operators would be provisioning a total of (105 Mbps *2 = 210 Mbps). When two operators are combined, the amount of over-provisioning is only 80% because we have now more users (*i.e.*, 500 in our example) and there is statistical multiplexing gain [BackhaulEfficiency] [Norros1] [Norros2]. The backhaul bandwidth to be provisioned for the combined operator would be (100 Mbps total average throughput * 1.8 = 180 Mbps). These are significant backhaul capacity savings: instead of 210 Mbps, the combined company needs to provision only 180 Mbps. Our preliminary analysis, based on the fiber lease costs specified in [Backhaul_Cost1], indicates that for this example a cost savings in excess of $1072 per month per cell-site could be realized (based on the fact that 30 Mbps lower bandwidth would need to be provisioned). In geographic areas where neither of the operators being merged has the required backhaul bandwidth, operating expense savings could be significant. The exact amount of cost savings is difficult to quantify because it depends on a variety of factors such as the number of subscribers, the average throughput, the target quality of service, the operator's backhaul provisioning philosophy, and the charging method of the fiber owner (*e.g.*, discrete levels of provisioned capacity and associated charges vs. incremental capacity and associated charges).

Side Note: Capacity Increase via Intercarrier Load Balancing – A Closer Look

When the downlink power is the main bottleneck, the capacity of a CDMA system can be estimated by [TripathiReed_CellularBook]

$$N = \frac{100 - P_{Overhead}}{P_{User}\, SPU}, \qquad (6.1)$$

where $P_{Overhead}$ is the percentage of the maximum power of the High Power Amplifier (HPA) (*e.g.*, 20%) allocated to the overhead channels, P_{User} is the average power allocated to a user in a cell (=sector) expressed as a percentage of the maximum power of the HPA, and SPU is the average sectors (=cells) per user. SPU specifies the number of sectors that the user communicates with. Since soft handoff (handover) is inherent in CDMA-based systems such as UMTS, SPU > 1 (*e.g.*, 1.4 to 1.8).

In CDMA systems, the signal-to-interference-plus-noise-ratio (SINR) required to achieve a certain quality of service (*e.g.*, 2% error rate) influences the achievable capacity. If required SINR is low, the power allocated to the user can be small, thereby increasing the capacity as dictated by Eq. (6.1). In contrast, higher required SINR would necessitate allocation of higher transmit power to the user, decreasing the capacity. SINR, and, in turn, the power allocated to the user dictates the capacity. As shown by Eq. (6.1), the available power ($100 - P_{Overhead}$) is distributed among N users. A load balancing algorithm that balances downlink power utilization across multiple carrier frequencies can accommodate more users by assigning the user a carrier frequency that has less loading. The longer it takes to reach the call blocking threshold, the higher the capacity can be, because more users could be admitted to the sector. In case of "unbalanced" carrier frequencies, the sector can support fewer users because the call blocking threshold will be reached sooner relative to the case of balanced carrier frequencies.

7. Improved Spectral Efficiency

AT&T has indicated that the ability to combine the spectrum of the two companies will yield a variety of different types of benefits in different circumstances, including the ability to shift certain spectrum to more spectrally efficient technologies, and also to increase the speed and quality of LTE. As explained in this section, we agree that the merger offers these types of efficiencies.

Newer technologies offer significant gains in spectral efficiency over older technologies. As AT&T and T-Mobile USA indicate, there will likely be a number of scenarios in which the combined company will be able to shift spectrum from a less efficient technology (either GSM or UMTS) to a more efficient one (either UMTS or LTE).

The merging parties have also explained that the integration of their networks will help them support GSM and UMTS subscribers during the multi-year migration to LTE, and we believe this is reasonable. When radio networks are upgraded to benefit from a more efficient newer-generation technology, not all subscribers upgrade their handsets to support the latest technology deployed by the service provider, even when offered incentives to do so. In our experience, it typically takes years for a legacy technology to be relegated to the pages of a history book. Even when the operators have launched or are launching superior fourth-generation LTE technology, they have to continue to support their existing legacy 2G and 3G technologies.

When two operators are independently running GSM and UMTS networks, they have less flexibility during the migration of the technologies, but a combined operator will have access to more spectrum which will facilitate a more seamless and accelerated technology transition. As an example, two operators providing basic GSM coverage to a small number of GSM-only subscribers in a large geographic area have to maintain GSM networks to support their existing customers even though they want to redeploy spectrum to more efficient UMTS and LTE networks. Because GSM is significantly less spectrally efficient than newer technologies, a handful of GSM subscribers that remain on the GSM network in an area can prevent a much larger number of non-GSM subscribers from experiencing enhanced services offered by UMTS and LTE technologies. A combined operator can reserve a common set of traffic channels, eliminate redundant BCCHs, and accelerate network migration from GSM to UMTS and LTE. The combined operator can more easily and quickly adapt to the dynamic and unpredictable migration of subscribers from a legacy technology to a newer technology more efficiently and seamlessly due to increased spectrum flexibility.

Finally, we also agree that the combined company's ability to combine spectrum should permit it to offer *better* LTE service. LTE is the emerging technology of choice for most cellular operators around the globe. Spectral efficiency of LTE is very high (*e.g.*, peak efficiency of 15 bits per second per Hertz when the full potential of Release 8 is exploited).

LTE uses a multiple access technique called OFDMA (Orthogonal Frequency Division Multiple Access), where the available channel bandwidth is divided into multiple narrowband frequency channels known as subcarriers. The user is allocated multiple "orthogonal" subcarriers. Since the subcarriers are "orthogonal" to one another, there is no interference among these subcarriers. The absence of interference among subcarriers enables LTE to squeeze in hundreds of subcarriers in a given channel bandwidth. Parallel transmission of data on numerous subcarriers gives superior peak data rates.

LTE uses scalable OFDMA. The larger the channel bandwidth is, the more subcarriers that exist. For example, there are 300 subcarriers in 5 MHz bandwidth, but there are *600* subcarriers in 10 MHz bandwidth. Therefore, a carrier can easily double the potential LTE speeds by doubling the bandwidth.

For these reasons, we agree that the ability of the combined company to combine spectrum holds the promise of offering more effective LTE services that can support higher speeds, which would facilitate a wide range of innovative services that would require higher throughput and lower latency.

8. Limited Availability Of Alternative Solutions.

Stravitz makes a series of claims to the effect that AT&T could solve its capacity issues by making better use of the spectrum and resources that it already has. In particular, he claims that he has a simple three-part prescription to solve AT&T's capacity issues: (1) AT&T has a substantial amount of spectrum lying "idle" that it should deploy to relieve exhaustion; (2) AT&T should actively migrate customers to more spectrally efficient technologies, which appears to mean that it should stop supporting handsets that use older technologies; and (3) AT&T should deploy a more "heterogeneous" network that makes increased use of microcells femtocells, WiFi (Wireless Fidelity), distributed antennae systems (DAS), increased sectorization, and other engineering techniques. Although these claims may sound reasonable at a superficial level, we do not see any basis in cellular engineering to believe that any of these strategies could alleviate AT&T's large-scale macro capacity issues.

Spectrum Use. Stravitz claims that AT&T "uses only roughly half of its licensed spectrum," and that AT&T could avoid capacity exhaustion by using more of this spectrum rather than leaving it "idle."[19] Stravitz never explains, however, how he thinks AT&T should be using this "idle" spectrum, and in fact it is difficult to fault AT&T's plans for this spectrum. Most of the "idle" spectrum is 700 MHz or AWS spectrum, but AT&T is actively in the process of using that spectrum to deploy a nationwide LTE network[20] – the most spectrally efficient technology available, just as Stravitz would presumably recommend. If AT&T were to use that spectrum now to deploy additional UMTS carriers, that spectrum would not be available for the more spectrally efficient LTE (and would have to be cleared of UMTS users before it could be used for LTE).

All spectrum technologies go through natural life cycles, and at any given time, major carriers are likely to have some "idle" spectrum as they prepare to deploy the next generation of technologies. That fact is unremarkable and a sign of prudent planning, not a sign that AT&T is "mismanaging" its spectrum.

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[19] Stravitz ¶ 7.

[20] http://www.bgr.com/2011/05/25/att-to-deploy-4g-lte-network-in-five-markets-this-summer/#utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+TheBoyGeniusReport+%28BGR+%7C+Boy+Genius+Report%29

Technology Shifting. Stravitz also claims that AT&T continues to promote handsets that rely on its older GSM and UMTS technologies, which he claims is precluding the migration of customers to more spectrally efficient technologies like HSPA+ and LTE.

First, he claims that AT&T is subsidizing and selling handsets that use 2G data technologies like EDGE and GPRS, which limits AT&T's "ability to take advantage of more spectrally efficient technologies like UMTS/HSPA+ and LTE."[21] Under any reasonable estimate, it will take years to migrate AT&T's tens of millions of GSM users (including many M2M devices) to other data networks, and the fact that AT&T may undertake some modest promotions of prepaid 2G data devices aimed at value-based customers is unlikely to prolong the life cycle of GSM in any material way.

In addition, Stravitz argues that AT&T is not a "prudent steward of its spectrum resources" because it has not already "pre-seeded" the marketplace with devices capable of running on its LTE network.[22] The fact that Qualcomm introduced a dual-mode chipset in late 2009, however, is of no real importance – it takes a long time for device makers to develop actual handsets that use such chipsets and, by Stravitz's own admission, such handsets have been available only since the first quarter of *2011 – i.e.*, until just a couple of months ago. Moreover, AT&T began selling LTE-capable laptop cards last year and it has already announced that it will be offering LTE handsets later this year.[23]

"Heterogeneous" Networks. Finally, Stravitz claims that AT&T could solve its spectrum problems if it would only make its network more "heterogeneous" and use more microcells, femtocells, WiFi, sectorization, smart antennas and software-defined radios. But AT&T's network *is* quite heterogeneous today, and although each of these technologies is perfectly appropriate to address very specific and limited situations, these types of technologies are simply not a feasible solution for the large-scale congestion that AT&T faces at the macro cell level.

First, AT&T has a heterogeneous network today that employs macro, micro, and femtocells, as well as DAS and Wi-Fi, and it will undoubtedly continue with this progression. However, these technologies have their limitations. For example, technologies like femtocells are used primarily to extend *coverage* (and user experience) not increase capacity. It would be prohibitively expensive and completely infeasible to make widespread use of femtocells in an attempt to relieve spectrum exhaust on macro cells. These tiny cells tend to be expensive because they

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[21] Stravitz ¶ 17.

[22] Stravitz ¶ 19.

[23] See AT&T News Release, "AT&T Announces its First LTE and HSPA+ Laptop Connect Devices," October 5, 2010 (announcing USBConnect Adrenaline laptop modem from LG and quoting AT&T as saying "We have purposefully planned our path to LTE to create a wireless network where the transition from 3G does not give customers wireless whiplash"). Stravitz's own example of "pre-seeding" is T-Mobile USA's introduction of an HSPA+ dongle *two months* before it began to offer HSPA+. Stravitz ¶ 18.

essentially implement most functionalities of a regular macro base station and must have a backhaul connection. Femtocells also have issues in providing the mobility support that a traditional macro cellular system provides. Mobility across macro cells usually involves reliable soft handover, while mobility across macro and small cells usually involves relatively less reliable hard handover in UMTS systems. Smaller cells make the handover process more complex, particularly when transiting between femotcells and the macro network, and create a significant amount of new signaling traffic, especially due to the use of different carrier frequencies on macro and small cells. The addition of a large number of femtocells also increases the possibility of interference to the macrocellular system. Similar issues exist for WiFi. Although these types of technologies will play an important role for all service providers, they are reserved for very acute problems involving relatively few customers and cannot provide the level of seamless mobility customers expect and that today's larger macro networks offer.[24]

In addition, contrary to Stravitz's claims, advanced antenna techniques (*e.g.*, Multiple Input, Multiple Output or "MIMO") and finer sectorization (*e.g.*, 60° sectorization instead of 120° sectorization) are not solutions to AT&T's capacity issues. These technologies, while worthwhile and appropriate for certain purposes, would be of little help to AT&T in addressing its current spectrum issues.

Technologies like MIMO and smart antennae are optimized for LTE networks[25]; smart antennae have not integrated well into 3G networks and have not been widely adopted. Moreover, these types of technologies are best used in certain specific environments, such as dense urban areas where there are a lot of buildings. Although AT&T and other LTE carriers can be expected to make intelligent use of these and other technologies in their LTE networks when and where they are appropriate, these technologies are no solution to AT&T's immediate problem, which involves seeking ways to relieve spectrum exhaust on its GSM and UMTS networks.[26]

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[24] Even though femtocells have their issues, we understand that AT&T has been aggressively exploring this technology and was the first to deploy 3G voice and HSPA data femtocells.

[25] High-performance antenna techniques are expected to become common only in LTE due to relatively simpler and less expensive antenna techniques for OFDMA systems (*e.g.*, LTE) and support of these antenna techniques by base stations and typical subscriber devices with clearly defined support in the standards.

[26] There is commercial support for some antenna techniques available for HSPA+, but not for pre-HSPA+ UMTS systems. The benefits even for HSPA+ would be very modest and depend on the proportion of HSPA+ subscribers to non HSPA+ subscribers. The antenna techniques that significantly improve throughput are spatial-multiplexing MIMO modes; however, these techniques only work well if the user is close to the site (*i.e.*, when signal-to-interference ratio is high) and the surrounding radio environment has "rich" multipath scattering. For this reason, this technique cannot be used in a significant area of the cell, and hence it will not yield significant throughput gains. Considering the cost, complexity, and relatively modest expected throughput gain of MIMO for HSPA+ in practice, many operators including T-Mobile USA and AT&T have decided not to use the MIMO feature of HSPA+.

While finer sectorization can increase capacity, it also significantly increases complexity in numerous ways. For example, a typical base station covers three sectors, but a network operator effectively needs two base stations to cover six sectors, which essentially doubles the base station cost. The operator would also need more space on the tower to place an additional three antennas, but not all cell-site structures can support six sectors. Finer sectorization also increases signaling load due to a higher degree of soft handover and it makes network optimization more complex (because the engineer has less flexibility to adjust where the antennae are pointed). And because it is much more difficult to contain energy within a sector in a six sector deployment, there is greater interference with other sectors (which reduces capacity). In short, although AT&T and other operators do occasionally deploy six sectors, the preferred solution is usually to add a new carrier frequency due to its simplicity and effectiveness.

Stravitz's suggestion that AT&T could address its spectrum capacity issues with LTE-Advanced standards is even more off the mark.[27] As he acknowledges, those standards are expected to be released in 2012. The adoption of standards, however, is just the beginning of a multi-year process. Furthermore, it is still too early to know what sorts of features and capabilities such equipment will support. There is no realistic possibility that LTE-Advanced standards for "heterogeneous" network features will be available to AT&T within any timeframe relevant to its current spectrum challenges.

Finally, we do not understand the suggestion that AT&T should make greater use of software-defined radios. All carriers, including AT&T, use these types of radios today, but they do not increase (or make more efficient use of) *capacity*. Software-defined radio approaches have been used at least since the 1990s for cellular base stations. They are quite useful in helping a carrier upgrade the technology in the base station, but they do not inherently provide any capacity gains over traditional implementations. The signals transmitted for software radios and more traditional radios are the same in both cases. Furthermore, pure software radio systems for LTE to our knowledge do not exist because the latencies in the MAC (Medium Access Control) layer are too tight for today's technology. Although these limitations may be overcome in the future, such technologies would not help AT&T overcome the capacity challenges that it faces today.

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[27] Stravitz ¶ 48.

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Jeffrey H. Reed, Ph.D.

Willis G. Worcester Professor of Electrical and Computer Engineering
Director of Wireless at Virginia Tech
The Bradley Department of Electrical and Computer Engineering
Virginia Tech
432 Durham Hall, Mail code 0350
Blacksburg, VA 24061
Voice: (540) 231-2972
FAX: (540) 231-2968
Email: reedjh@vt.edu
www.wireless.vt.edu

Vitae

Section I: Experience & Education

Current Position:

Director of Wireless at Virginia Tech (Wireless@VT), 2005-present
Professor of the Bradley Department of Electrical and Computer Engineering, June 2002- Present
Interim Director, The Ted and Karyn Hume Center for National Security and Technology, January 2010 – May 2011
President, Power Fingerprinting, Inc 2010-present
CTO, Cognitive Radio Technology, 2007-present
Willis G. Worcester Professor of ECE, 2005-present

Professional Interest:

Research and teaching in signal processing and communication systems

Specific Research Interests	**Specific Teaching Interests**
Software Radios	Software Radios
Smart Antennas	Digital and Analog Communications
Interference Rejection	Discrete Time and Digital Signal Processing
Wireless Networks	Cellular and Personal Communications
Cognitive Radio	DSP-based Communication System Design
Location Technology	Adaptive Filtering

Education:

Ph.D.
Electrical and Computer Engineering, December 1987, University of California, Davis
Awarded American Electronics Fellowship for Faculty Development
Major: Statistical Signal Processing; Minor: Control Systems and Statistics
Dissertation: *Interference Rejection Using Time-Dependent Adaptive Filters*
Attended part-time at University of Santa Clara, September 1980 through June 1983

M.S.
Electrical and Computer Engineering, June 1980, University of California, Davis
M.S. Project Topic: An EEG Data Acquisition and Analysis System

B.S.
Electrical and Computer Engineering, March 1979, University of California, Davis

Employment:

Professor, Virginia Tech, April 2001-present
Director, MPRG 200-2002
Associate Professor, Virginia Tech, 1997-2001
CTO and co-founder, Cognitive Radio Technologies, 2007-present
Co-founder, Dot Mobile, Inc., March 2000-2001
Consultant, Reed Engineering (Self-Employed), 1987-present
Assistant Professor, Virginia Tech, 1992-1997
Research Engineer, University of California, Davis, 1992
Lecturer, University of California, Davis, 1988-1992
Associate Instructor, University of California, Davis, 1985-1987
Teaching Assistant, University of California, Davis, 1984-1985
Member of Technical Staff, Signal Science, Inc., Santa Clara, CA and Hanover, MD, 1980-1985

Professional Affiliations:

Member of **Tau Beta Pi Honor Society**
Member of **Phi Kappa Phi Honor Society**
Member of AFCEA
Fellow of the IEEE

Professional Awards:

Named Willis G. Worcester Professor of ECE, summer 2005, Fall 2010
Industry Achievement Award, SDR Forum 2004
Institute of Electrical and Electronics Engineers Fellow, Dec. 2004
Virginia Tech College of Engineering Outstanding Researcher Award, 2001

Section II: Funded Research
(Principal Investigator or Co-Principal Investigator)

SDR Technology Development Support, Maryland Procurement Office, 9/30/10 – 9/29/2010 $1,562.300

Mobile Cognitive Radio Testbed, ICTAS, 7/1/10 – 6/30/11 $213,566 (co-PI)

Experimental Develoment Capability for Software Defined Radio with Agile Hardware, ONR, 1/27/2010 – 1/26/2011 co-PI)

Collaborative Research: Enhancing Access to the Radio Spectrum (EARS) Workshop, NSF 4/15/2010 – 03/31/2011 $21,860.00

Recommendations for Transitioning Silvus MNM FPGA Core IP, DARPA (Silvus Technologies) 2/18/2010 – 2/17/2011, $39,970.00 (co-PI)

Updates to OSSIE Core Framework to Enhance Compatibility with Open CPI, Mercury Federal Systems 4/8/10 - $39,998.00 (co-PI)

NSWC-TO13-Wireless Distributed Computing: Concept to Reality, Naval Secure Warfare (DARPA) Center 6/22/2010 - $498.798.00

Autonomous Cognitive Mobile Robotic Radio Network Testbed, Defense University Research Instrumentation Program (DURIP), 9/9/2010 - $361.786.00

Investigating the Relationship of OSSIE to Higher Layers, NSF 8/1/2009 – 2/28/10 $76,040

VT-Cornet: Virginia Tech Congitive Radio Network, ICTAS, 7/1/08 – 6/30/09 $142,580

Cryptographic API and Subsystem Simulator, SCA Technica, 1/1/09 – 9/26/09 $39,000

Cognitive Radio Network Testbed Instrumentation, Office of Naval Research, 4/15/09 – 4/14/10 $347,979

VT-Cognet: Virginia Tech Cognitive Radio Network Testbed Phase 2, ICTAS 1/12/09 – 1/11/10 $149,959 (co-PI)

CT-ISG: Assuring Security in Spectrum Agile Radio Networks, NSF, 01/01/07 - 12/31/10 $499,997 (co-PI).

Improved Distribution and Error Recovery of the OSSIE Core Framework, SAIC 3/01/2009 – 9/30/2009 $75,000

IC CAE: Emerging Tehcnologies IC CAE, Howard University 9/23/2009 – 9/22/2011 $2.5M

REU Supplement to award #0520418 Nets: Oriwub:An Open Systems Approach for Rapid Proto-typing Waveforms for Software Defined Radio, NSF $41,800

Nets Prowin: An Open Systems Approach for Rapid Prototyping Waveforms for Software Defined Radio, National Science Foundation, 8/1/08 – 7/31/09 $12,000 (asking for additional REU funding)

Enhancements to OSSIE: (Open Source SCA Implementation: Embedded), Science Applications International Corporation, 4/1/07 – 90/07 $75,000

Collaborative Research: CT-T TRIESTE: A Trusted Radio Infrastructure For Enforcing Spectrum Etiquettes, NSF, 10/01/07 – 9/30/10, $150.000 (Reed Co-PI)

Development Design of a Cognitive Engine and Anyalysis of WRAN Cognitive Radio Algorithms, ETRI, 7/01/07 – 12/31/07 $119,999

An Integrated Tool for SCA Waveform Development, Testing, and Debugging and A Tool for Automated Estimation of DSP Resource Statistics for Waveform Components, US-Army-CERDEC Office, 6/12/07 – 6/11/08, $326,125

Software Defined Radio Waveform and Device Development and Component Deployment Using OSSIE, DOD, 7/19/07 – 7/18/10, $975,639 ($184,744 awarded to this point)

Reasoning and Learning in Adapative Wireless Networks, BBN Technologies, 10/1/07 – 12/31/10, $913,196 (co-PI)

US/Ireland International Workshop on Next Generation Open Architectures for Software-Defined Radio, NSF, 9/15/07 – 8/31/08, $35,963

VT-CogNet: Virginia Tech Cognitive Radio Network, ICTAS, 1/1/08 – 6/30/09,$160,170 (Reed, Bose PIs)

Trade Study Of Implementation of SDR: Fundamental Limitations and Future Prospects (DARPA SEED), US Army Aviation & Missile Command, 9/11/07 – 6/30/08 (Reed PI) $115,364

Distributed Computing for Collaborative Software Radio, Office of Naval Research, 02/05/07 - 02/04/10, $533,722 ($108,728 awarded first year)

A Panel of Commercial GSM Experts For Supporting JIEDDO Operations, JIEDDO, 12/18/06 - 2/28/07 $38,275

Cognitive Radio Test-bed, Virginia Space Grant Consortium, 08/16/06 - 08/15/07 $5,000

Emerging Wireless Technologies (EWT) Technology Assessment, Rosettex, 07/03/06 - 12/31/07 $91,000

Development of a Cognitive Engine and Analysis of WRAN Cognitive Radio Algorithms, ETRI, 06/16/06 - 12/31/06 $175,554.

Wireless@Virginia Tech Group Start-up, Institute for Critical Technology and Applied Science – ICTAS, 01/01/06 - 06/30/07 $500,000.

A Low-Cost All-Band/All-Mode Radio for Public Safety, National Department of Justice (Dept. of Justice), 10/01/05 - 09/30/08 $399,816 (Reed Co-PI)

Applying Artificial Intelligence Techniques to the Development of a Cognitive Radio Engine: Assessment, Evaluation, and Implementation, Army Research Office, 10/01/05 - 06/30/06 $49,995.

Analysis of WRAN Algorithms, ETRI, 10/01/05 - 12/31/05 $86,275

NeTS PROWIN: An Open System Approach for Rapid Prototyping Waveforms for Software Defined Radios, 08/15/05 - 08/14/09 $999,995 (Reed Co-PI)

Cognitive Radios, Virginia Space Grant Consortium, 08/10/05 - 08/09/06 $5000

A Software Defined Ultra Wideband Communication System Testbed, Virginia Space Grant Consortium, 08/10/05 - 08/09/06 $5,000

Advanced Wireless Integrated Network: AWINN, Office of Naval Research, 12/20/04 - 06/24/06 $484,200 (Reed portion)

Software Defined Radios: Evolution and Application Areas, Booz Allen Hamilton, 1/1/05 - 3/15/05 $74,497

Ossie and Harriet, SAIC, 08/16/04 - 12/31/05 $300,519

CDMA 2000 System Modeling and Simulation Program, Magnolia Broadband, Inc.***,*** 12/15/03 - 12/14/04 $84,500

Policy-based Resource Management in a Vehicular Ad-Hoc Network for First Responders, Naval Postgraduate School, 09/24/03 - 09/30/04 $25,431

System Level Design Approach and Methodologies For Software Defined Radios, National Imagery and Mapping Agency, 7/25/03 - 7/24/06 $189,282

Smart Antennas Research At The MPRG, Army Research Office, 06/01/03-12/31/04 $37,500

Proposal for GDDS Cluster X-SCA-Lite Architecture, General Dynamics, 05/01/03-10/31/03 $85,691.

Game Theoretic Analysis Of Radio Resource Management For Ad-Hoc Networks, Office of Naval Research, 04/01/03-03/31/06 $589,411.

***Game Theory in Radio Resource Management**, *Motorola University Partnership in Research, 09/01/02 - 05/31/04 $60,000

Software Radios and Smart Antennas: Challenges for Creating Seamless Networks, *Samsung Electronics, 04/08/03 - 05/15/04 $520,785*

UWB Propagation Measurements, Modeling, and Communication System Enhancements, DARPA, 08/16/01 - 12/31/03 $688,620

Tactical Communications Architecture and Implementation Plan for the U.S. Customs Service, Naval Surface Warfare Center, Dahlgren, 8/16/01 - 8/15/02 $402,000

ACN Independent Innovative Research Component, Raytheon Systems, 12/1/01 - 11/30/02 $11,250

Foundation Wireless Network for Medical Applications, Carilion Biomedical Institute, 8/6/01 - 8/10/02 $75,000

Interference, Propagation, and Antenna Placement Issues for XM Radio, GM, 3/26/01 - 9/25/02 $583,527

AOL Fellowship in Wireless Home Networking Technologies, AOL, 01/01/01 - 05/15/03 $84,583

Reconfigurable Apertures and Space-Time Processing, Raytheon Systems, 05/00 - 09/02 $841,350

Advanced Wireless Technology for Aerospace Communications, Virginia Space Grant Consortium, 08/00 - 05/03 $15,000

Research and Development for IMT-2000, LG Electronics, 05/15/00 - 09/31/01 $350,000

Motorola University Partnership in Research: Overloaded Array Processing, Motorola, 09/01/00 - 08/31/02 $84,944

Multiuser Detection for Overloaded Antenna Arrays, Raytheon, 05/00 - 05/02 $1,126,194

An Investigation of Base Station Diversity For Cellular Applications - Phase II, Metawave, 02/29/00 - 02/28/01 $104,000

Broadband Channel-Adaptive Radio Modem for NGI Network Extension and Access, Hughes Research Laboratory, 10/01/99 - 11/30/01 $81,412

Research Into Signal Recovery Algorithms in Support of Spectral Spatial Interference Cancellation System (SSICS) – Phase II Research Effort, Raytheon Company, 02/01/00 - 05/15/01 $149,756

Navy Collaborative Integrated Information Technology Initiative (NAVCIITI), Office of Naval Research, 04/00 - 06/04 $9,651,087 (Reed portion $534,089)

Research into Spatial Signal Recovery Algorithms in Support of Spectral Spatial Interference Cancellation System - Phase I (SSICS), Raytheon Company, 080/2/99 - 01/10/00 $97,857

Low Power and Robust Communications Using Hand-Held Smart Antennas for Receiving and Transmitting, Texas Instruments, 07/01/98 - 06/30/00 $331,993

An Investigation of Base Station Diversity for Cellular Applications, Metawave Communications, 03/01/99 - 02/28/01 $179,706

International Wireless Communication Research Program, Virginia Tech Research and Graduate Studies' SEED Program, 01/01/99 to 06/30/00 $7,500

Navy Collaborative Integrated Information Technology Initiative (NAVCIITI), Office of Naval Research, 11/14/98 - 09/30/00 $2,700,000.

Enhancing the Capacity of IMT-2000 Through Turbo Coding and Smart Antennas, LGIC, 10/01/98 - 09/30/99 $122,904

Low Power and Robust Communications Using Hand-Held Smart Antennas for Receiving and Transmitting, Texas Instruments, 07/01/98 - 06/30/99 $132,000

Techniques for Evaluating Location Technologies, Comcast, 05/01/98 - 12/31/98 $112,154

Development of Tools for CDMA Cellular Network Planning, Innovative Global Solutions (IGS), 04/01/98 - 01/31/99 $42,889

Configurable and Robust Wireless Communications Nodes, DARPA, 07/01/97 - 12/30/00 $2,015,431

Support of Telelink System Test, Global-Net, Inc., 09/25/96 - 09/24/97 $50,000

Sprint RFI and Evaluation, Sprint Spectrum L. P., 09/26/96 - 12/31/96 $31,158

Rural MayDay/800 Call-in System Feasibility, I-95 Corridor Coalition/ Virginia Department of Transportation, 02/01/96 - 01/31/97 $299,176 (MPRG share $157,988)

A Study of Reconfigurable Receivers for Cellular and PCS, Texas Instruments, 08/25/95 - 08/25/96 $35,000

CDMA/FM Evaluation Effort, Comdial Corporation/Sigtek, 08/28/95 - 12/31/95 $25,000 (plus $7,500 CWT match)

Measured DECT System Performance in Actual Radio Channels, National Semiconductor, 10/01/94 - 2/15/96 $35,024

Investigation of BMP Impacts on Nonpoint Source Pollution Using System Analysis Procedures, Virginia Water Resource Center/U.S. Dept. of Interior, 04/01/95 - 04/30/96 $9,963

Development and Implementation Of Interference Rejection Techniques for Cellular Communications, SAIC, Center for Wireless Telecommunications (CWT), $50,000 (SAIC, 03/22/95 to 12/31/95) $25,000 (CWT, 07/01/95 to 06/31/96)

Expanded Testing of a High Capacity Adaptive Wireless Receiver, ARPA/AASERT, 08/01/95 - 07/31/98 $125,522

Co-Channel Interference Rejection for FM Mobile Phone Systems, Motorola, 01/16/95 - 09/15/9, $33,000

Curriculum Innovation for Simulation and Design of Wireless Communications Systems, National Science Foundation, 08/16/95 - 07/31/98 $289,291

A High Capacity Wireless Receiver Implemented with A Reconfigurable Computer Architecture, ARPA/WAMIS, 09/94 - 08/30/97, $1,727,230 ($533,250 for the first year, $586,750 second year)

Development of a Low Power High Data Rate Spread-Spectrum Modem, Grayson Electronics, Virginia's Center for Innovative Technology (CIT), Center for Wireless Telecommunications (CWT), $29,833 (Grayson, 03/01/94 - 11/30/94), $13,204 (CIT, 03/01/94 - 10/31/94) and $16,000 (CWT matching funds, 04/01/94 - 06/30/95)

Rejection of Interference in AMPS Cellular Communication, ARGO Systems, VA's Center for Innovative Technology (CIT), $25,000 (ARGO Systems, 12/10/93 - 05/10/94) and $12,500 (CIT, 04/01/94 - 07/31/94)

Capacity and Interference Resistance of Spread-Spectrum Automatic Vehicle Monitoring Systems in the 902-928 MHz Band, Southwestern Bell Mobile Systems, 10/01/93 - 08/15/94 $70,007

University Road Connection - A Smart Highway, Virginia Dept. of Transportation, 07/01/94 - 11/01/94 $19,523.79

Development of a Spread Spectrum Transceiver for the DECT System, National Semiconductor, 07/01/94 - 06/30/95 $30,000

Investigation of a Dynamic Range Enhancer for an Electro-optic Interface, Southwestern Bell Technology Resources, Inc., 08/01/93 - 06/01/94 $45,000

IVHS Research Center of Excellence, Federal Highway Administration (FHWA), 1993 - 1998, $1 million/year for 5 years (MPRG total approximately $390,000 over performance period, $330,000 received in 93-94, 94-95, 95-96, 96-97 contract years)

Center for Wireless Communications, Center for Innovative Technology, 09/01/93 - 08/31/98, $300,000 for first year. (Anticipated total funding approximately $1,490,835 plus an additional $357,551 of cost sharing by Virginia Tech)

The Performance and Feasibility of Time-Dependent and Non-Linear Adaptive Filters for Rejecting High-Power Co-Located Co-Channel Interference, US Navy via Systems Research Center, 05/15/93 - 09/01/93, Amount: 1/2 summer session support (value approximately $3,750)

Evaluation of an NTP-Based Protocol for Paging and Advanced Data Services, MobileComm, 07/01/93 - 09/30/93 $39,986

Grants & Gifts:

Ted and Karyn Hume center for National Security and Technology Endowment Fund January 2010, $5,000,000 (Note that most of this money goes for student fellowships, with $200k provided for center support.)
Total Amount - $5,209.010.00

Intel – Jan. 2010, gift for unrestricted research $50,000.00

Tektronix, reconditioned real time spectrum analyzer and two portable analyzers, ~ $130,000

Tektronix - Dec. 2009, reconditioned Arbitrary Function Generator, 100 Mhz, 2 Channel $5,110.00

Wireless@VT Industrial Affiliates Membership 2006-2009:

Affiliate Funding for the year 2009 – 2010 for Dr. Jeffrey H. Reed is $66,960.
Affiliate Funding for the year 2008 - 2009 for Dr. Jeffrey H. Reed is $40,534

Intel Coporation:: 2009 to support the research in "Cognitive Radio for Minimizing Power Consumption" $44,000

Tektronix*,* 12/2005, cash gift $20,000

Texas Instruments*,* 08/2005, cash gift $27,519

Tektronix, 07/2005, cash gift $20,000

Texas Instruments. 12/2004, cash gift $99,000

Tektronix, spring 2004, cash gift $20,000

CISCO Systems, 08/2003 and 02/2005, cash gift $176,000

Mercury Computer Systems, Inc., 2003, cash gift $50,000

Analog Devices, 2001-2002*,* cash gift $37,500

HRL, ***Smart Antenna Research,*** 2000, cash gift $40,000

Rockwell, Flexible Communications Using Reconfigurable Computing, 1998, $25,000 cash gift

Investigation of CDMA, donation from ITT, 1996, cash gift $100,000

MPRG Industrial Affiliates Membership 1993-2006: Grant total split between the five MPRG faculty (total paid $4,866,500 and an additional $110,000 committed to date). Services provided to sponsors include advanced copies of thesis and dissertations, informal consulting, and special opportunities to employ students.

Intel, 10/2007, $40,000, Support research in "Cognitive Radio for Minimizing Power Consumption," 5/2008, $44,000

Texas Instruments, Evaluation Module Kit, 01/2007, $995

Tektronix, Arbitrary Waveform Generator, 02/2007, $138,000.

Xilinx, Inc., Xilinx System Generator, ChipScope Pro, Xilinx Real-PCI interface, AccelDSP Synthesis Tool with AccelWare DSP IP Toolkits, VLYNQ Interface LogiCORE, ISE Foundation, University Option Embedded Development Kit, 01/2007, $39,615

Tektronix, equipment, $114,000

Texas Instruments, 06/2006, $49,500

Mercury Systems, AdapDEV 1280 Chassis with 900 MHz processor, 08/2003

Spectrum Signal Processing, Inc., Hardware necessary to implement a true software defined radio, 08/2002, $62,329

Grayson Wireless, Cellular test and measurement system, 08/2002, $66,312

Signia-IDT (formerly BAE), RF Front-end valve, 2002, ~$6,000

Altera, MAX + Plus II Fixed Node Subscription (FPGA board), $2,000

Texas Instruments, Evaluation Module incl. Code Composer Studio, 06/2001, $19,960

Texas Instruments, ADC-Converter, 03/2001, $99

Analog Devices, Evaluation Boards (5), Visual DSP software (2), In-Circuit Emulators (2), $3,790

Wireless Valley Communications, 2 copies SitePlanner w/LanFielder $49,980, 1 copy SiteSpy on SMT $995, 2005, $50,975

Analog Devices, receiver, processor, and receiver chip set, $645

Texas Instruments, boards, 2001, $2,495

HRL, 2000, Diversity Antenna, $200

Altera, development package, 2000, $995

Altera, (2) MAX+ PLUS II Fixed Node Subscription for PC, (1) design lab package, (1) Micro-Chip; $4,765

Motorola, 56311EVM computer board with DSP and 56311 on it, software, documentation, tutorial, and input/output capabilities, 12/2000, $2000

Texas Instruments, Evaluation software and manuals, 1998, $2,500

Texas Instruments, Evaluation Software, 1997, $1,000

Altera, Development Tools for Programming Configurable Logic Devices, $350

Texas Instruments, DSP Development Systems and Software, 1997, $11,475

Texas Instruments, DSP Hardware and Software, 1997, $27,500

Analog Devices, DSP Development Boards, 1996, $3,200

Altera, Software Materials, 1996, $5,000

SIGTEK, Spread Spectrum Receivers, 1995, $10,000

Section III. Teaching & Advising

Classes Taught:

Graduate Courses

Cellular and Personal Communications (ECE6644)
Software Radios: A Modern Approach to Radio Engineering (ECE5674)
Digital Signal Processing (ECE5624)
Cellular (ECE 5664)

Undergraduate Courses

Implementation of Communication Systems (ECE4654)
Signal Processing (ECE4624)
Communication Systems (ECE3604)

Courses Developed:

Major Revision of ECE course 5664 to focus on systems level description and design considerations of cellular standards this will take two more years to complete and result in a textbook.
Implementation of Communication Systems (ECE 4654)
(Lab materials also developed)
Software Radios (ECE 5674)
Major Revisions on over half of lecture material (ECE 5664)

Advising: Completed Ph.D. Dissertations:

Lizdabel Moarles Tirando, "An Approach to Using Cognitive in Wireless Nwtworks," December 2009

Kyou Woong Kim, "Exploiting cyclostationarity for radio environmental awareness in cognitive radios," May 2008

Youping Zhao, "Enabling cognitive radios through radio environment maps," May 2007

Rekha Menon, "Interference avoidance based underlay techniques for dynamic spectrum sharing," April 2007 (co-advised with Dr. Michael Buehrer)

Jong-Han Kim, "On the impact of MIMO implementations on cellular networks: An analytical approach from a system perspective," March 2007

Ramesh Chembil Palat, "Performance analysis of cooperative communications for wireless networks," December 2006

Jody Neel, "Analysis and design of cognitive radio networks and distributed radio resource management algorithms," September 2006

Chris Anderson, "A software defined ultra wideband transceiver testbed for communications, ranging, or imaging." September 2006

James Hicks, "Novel approaches to overloaded array processing," August 2003

Raqibul Mostafa, "Feasibility of smart antennas for the small wireless terminals," April 2003

William Newhall, "Radio channel measurements and modeling for smart antenna array systems using a software radio receiver," April 2003

Pablo Max Robert, "Reduction in coexistent WLAN interference through statistical traffic management," April 2003

Tom Biedka, "Analysis and development of blind adaptive beamforming algorithms," August 2001

Srikathyayani Srikanteswara, "Design and implementation of a soft radio architecture for reconfigurable platforms," July 2001

Rich Ertel, "Antenna array systems: Propagation and performance," July 1999

Nitin Mangalvedhe, "Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems," July 1999

Nishith Tripathi, "Generic handoff algorithms using fuzzy logic and neural networks," November 1997

Paul Petrus, "Novel adaptive array algorithms and their impact on cellular system capacity," April 1997

Jeff Laster, "Robust GMSK demodulation using demodulator diversity and BER estimation," January 1997

Rong He, "AMPS co-channel interference rejection techniques and their impact on system capacity, August 1996

Completed M.S. Theses:

Sabares S. Moola defended his master's thesis, "Rapid Prototyping of Software Defined Radios using Model Based Design for FPGAs," on July 22, 2010

Ishtiaq Rouf, "Statistical Analysis of Wireless Communication Systems Using Hidden Markov Models," July 2009

Matthew Carrick, "Logical representation of FPGA's & FPGA circuits within the SCA," July 2009

Patrick Farrell, "Digital hardware designing decisions & trade-offs for software radio systems," May 2009

Philip Balister, "A software defined radio implemented using the OSSIE core framework deployed on a TI OMAP processor." December 2008

Jacob DePriest, "A practical approach to rapid prototyping of SCA waveforms," April 2006

Srinivasan Vasudevan, ”A simulation for analyzing the throughput of IEEE 802.11b wireless LAN systems,” January 2005

Brian Donlan, "Ultra-wideband narrowband interference cancellation and channel modeling for communications," January 2005

Anil Hebbar, "Empirical approach for rate selection in MIMO OFDM," December 2004

Seshagiri Krishnamoorthy, "Interference measurements and throughput analysis for 2.4 GHz wireless devices in hospital environments," April 2003

Yasir Ahmed, "A model-based approach to demodulation of co-channel MSK signals," December 2002

Ramesh Chembil Palat, "VT-Star – Design and implementation of a test bed for differential space-time block coding and MIMO channel measurements," October 2002

Jody Neel, "Simulation of an implementation and evaluation of the layered radio architecture," December 2002

Bing-Leung (Patrick) Cheung, "Simulation of adaptive algorithms for OFDM and adaptive vector OFDM systems," August 2002

Shakheela H. Marikar, "Resource management in 3G systems employing smart antennas, January 2002

M. Soni, "Computing engine for reconfigurable software radio," Oct. 2001

Christian Rieser, "Channel sounder for LMDS," May 2001 (co-advisor)

James Hicks, "Overloaded array processing with spatially reduced search joint detection," May 2000

Zhong Hu, "Evaluation of joint AOA and DOA estimation algorithms using the antenna array systems," May 1999

Kim Phillips, "Probability density function estimation for minimum bit error rate equalization," May 1999

Pablo (Max) Robert, "Simulation tool and metric for evaluating wireless digital video systems," May 1999

Steven F. Swanchara, "An FPGA-based multiuser receiver employing parallel interference cancellation," July 1998

Don Breslin, "Adaptive antenna arrays applied to position location," August 1997

Steve Nicoloso, "Investigation of carrier recovery techniques for PSK modulated signals in CDMA and multipath mobile environments," May 1997

Brian Fox, "Analysis and dynamic range enhancement of the analog-to-digital interface in multimode radio receivers," February 1997

Nena Zecevic, "Interference rejection techniques for the mobile unit direct-sequence CDMA receiver, August 1996

Kevin Saldanha, "Performance evaluation of DECT in different radio environments," August 1996

Milap Majmundar, "Adaptive single-user receivers for direct sequence CDMA systems," February 1996

Yash Vasavada, "Performance evaluation of a frequency modulated spread spectrum system," February 1996

Scott Elson, "Simulation and performance analysis of CDPD," January 1996

Matthew Welborn, "Co-channel interference rejection using model-based demodulator," January 1996

Francis Dominique, "Design and development of a frequency hopper based on the detection system for the 902-928 MHz ISM band," December 1995

Nitin Mangalvedhe, "An Eigenstructure technique for direct sequence spread spectrum synchronization," April 1995

Paul Petrus, "Blind adaptive arrays for mobile communications," December 1994

Sihano (Raymond) Zheng, "Channel modeling and interference rejection for CDMA automatic vehicle monitoring systems," November 1994

Fu-Sheng (Frank) Cheng, "A new approach to dynamic range enhancement," September 1994

Volker Aue, "Optimum linear single user detection in direct-sequence spread-spectrum multiple access systems," March 1994

Current Ph. D Students:

Carlos Aguayo Gonzalez – Ph.D expected completion date December 2010

Ashwin Amanna – Ph.D expected completion date May 2012

Sounava Bera – Ph.D expected completion date May 2013

Xuetao Chen – Ph.D (Co-Advised Dr.Bose and Dr. Reed) completion date March 2011

Dinesh Datla – Ph.D expected completion date May 2011

Manik Gadhiok – Ph.D expected completion date July 2011

Joseph Gaeddert – Ph.D expected completion date August 2010

An He – Ph.D expected completion date December 2011

Benjamin Hilburn – Ph.D expected completion date December 2012

Eyosias Iman – Ph.D expected completion date December 2012

Sahana Raghunandan – Ph.D expected completion date July 2011

Kunal Rele - Ph.D – expected completion date December 2012

Karim Said – Ph.D expected completion date May 2012 (currently at the Egypt campus)

Abid Ullah – Ph.D expected completion date December 2012

Matthew Vondall Pd.D – (Co-Advised/Amir Zaghoul) expected completion date May 2011

Hazem Shatila - (Co-Advised/Dr. Mohamed Khedr at VT MENA) expected completion date March 2011

Current M.S. Students:

Michael Benonis – M.S. expected completion date May 2011

Thomas Cooper – B.S./M.S. expected completion date May 2012

Shawn Hymel – M.S. expected completion date May 2011

Hermie Mendoza – M.S. expected completion date May 2011

Matthew Price – M.S. expected completion date May 2011

Peter Sahmel – M.S. expected completion date January 2011

Thomas Tsou – M.S. expected completion date December 2012

Section IV. Publications List

Books Authored or Co-Authored:

1. J. H. Reed, ed., An Introduction to Ultrawideband Communications Systems, Prentice Hall, March 2005, ISBN: 0-13-148103-7.

2. J. H. Reed, Software Radio: A Modern Approach to Radio Design, Prentice Hall, May 2002, ISBN: 0-13-081158-0.

3. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, Radio Resource Management in Cellular Systems, Kluwer Academic Publishers, Spring 2001.

Books & Proceedings Edited:

1. "The Radio Environment Map", (Book Chapter) Cognitive Radio Technology, Dr. Bruce Fette, ed., Y. Zhao, S. Mao, J. Neel, and J.H. Reed2nd edition, 2 April 2009

2. J. Neel. J. Reed, A. MacKenzie, Cognitive Radio Network Performance Analysis in Cognitive Radio Technology, B. Fette, ed., Elsevier, 2nd edition, 2 April 2009.

3. W. H. Tranter, B. D. Woerner, J. H. Reed, T. S. Rappaport, and P. M. Robert, Wireless Personal Communications – Bluetooth and Other Technologies, Kluwer Academic Publishers, 2000.

4. W. H. Tranter, B. D. Woerner, T. S. Rappaport, and J. H. Reed, Wireless Personal Communications – Channel Modeling and Systems Engineering, Kluwer Academic Publishers, 1999s.

5. W. H. Tranter, T. S. Rappaport, B. D. Woerner, and J. H. Reed, eds., Wireless Personal Communications: Emerging Technologies for Enhanced Communications, Kluwer Press, 1998.

6. T. S. Rappaport, B. D. Woerner, J. H. Reed, and W. H. Tranter, eds., Wireless Personal Communications: Improving Capacity, Services, and Reliability, Kluwer Press, 1997.

7. J. H. Reed, B. D. Woerner, and T. S. Rappaport, eds., Wireless Personal Communications: Advances in Coverage and Capacity, Kluwer Press, 1997.

8. T. S. Rappaport, B. D. Woerner, and J. H. Reed, eds., Wireless Personal Communications: The Evolution of PCS, Kluwer Press, 1996.

9. B. D. Woerner, T. S. Rappaport, and J. H. Reed, eds., Wireless Personal Communications: Research Developments, Kluwer Press, 1995.

10. T. S. Rappaport, B. D. Woerner, and J. H. Reed, editors, Wireless Personal Communications: Trends and Challenges, Kluwer Press, 1994.

Book Contributions:

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Papers, Talks, & Lectures Presented at Professional Meetings:

1. Keynote Presentation, "The Future of Cognitive Radio," Univ of Texas and Austin Technology Incubator. A group of faculty and VCs.

2. Invited Presentation, "The Second Wave of Wireless: A New Wave of Disruptive Technology," Atlantic Council (DC think-tank) to help inform international decision makers, Oct. 2010.

3. Cognitive Wireless Networking (CoRoNet), Keynote Speaker, Chicago, Illinois, September 20, 2010

4. The Ted & Karyn Hume Center Inauguration Reception and Board Meeting, Arlington, VA August 18, 2010.

5. Invited talk, "Cognitive Radio Research at VT," ISART, NTIA, July 2010.

6. DoD Technical Exchange Meeting at the Finnish Embassy under the aegis of the Secretary of Defense, Washington D.C. May 2010

7. Speaker, Oak Ridge National Laboratory Board of the Governors, May 2010

8. JASON, an independent group of scientists which advises the United States Governement on matters of science and technology - San Diego, CA May 2010

9. Dr. Jeffrey Reed and Dr. Nishith Tripathi, *Wireless Net Neutrality Regulation: A Response to Afflerbach and DeHaven, March 2010*, submittedd to the FCC.

10. Jeffrey H. Reed & Nishith D. Tripathi, *The Application of Network Neutrality Regulations to Wireless Systems: A Mission Infeasible,* submitted to the FCC, Jan. 2010

Note the two reports above are *responses to the FCC Notice of Proposed Rule Making on Network Neutrality (a highly controversial subject that poses a major threat to the US wireless industry)*

11. "The Nexus of Security and Technological Leadership, Deemed Export Rule Recommendations and Zero-based Methods to Identify Technologies that Require Deemed Export Control', Submitted to the Security of Commerce by the Emerging

Technologies and Research Advisory Committee, A Federal Advisory Committee Appointed by the Secretary of Commerce To examine EARS Regulations. 2009.

Note current EARS regulations currently represent a major challenge to US industry and academia for engaging international personnel in research and this committee addressed this challenge.

12. Institute for Defense and Government Analysis Conference – Security Issues in Cognitive Radio, 2010.

13. Army Research Lab Seminar, Sept. 2009

14. Lectured VT-MENA in Alexandria, Egypt Nov. 2009

15. Technical seminar at Cairo University, Nov. 2009

16. Presented to NTIA, the telecom regulatory authority in Egypt, Nov. 2009

17. Korean US Communications Technology Symposium, July 2009

18. Finnish Embassy – US Military Collaboration with Finnish Government, March 10-11, 2008

19. Institute for Defense and Government Analysis Conference -- VT's Cognitive Radio and Security Research, March 2009

20. J. H. Reed, IEEE presentation to the IEEE San Diego Section, April 7, 2009 San Diego, CA.

21. J. H. Reed, "Distributed computing in collaborative software radio," presented to the Office of Naval Research, May 1, 2007.

22. J.H. Reed, Keynote Speaker at the *Communications Technology Program Review, Planning Assessment Meeting*, "Distributed computing for collaborative software defined radio," Naval Research Laboratory, May 2007.

23. J. H. Reed, "Issues in cognitive wireless networks," talk presented at the *Intel Research Forum Seminar Series*, Portland, OR, March 28, 2007.

24. J. H. Reed, "Issues in cognitive wireless networks," talk presented at NIST, March 2, 2007.

25. J. H. Reed, "Understanding the issues in software defined cognitive radios," seminar presented at the University of Pennsylvania, October 16, 2006.

26. J. H. Reed, "Issues in cognitive wireless networks," talk presented at the *IEEE Workshop Networking Technologies Software Defined Radio (SDR) Networks*, (held in conjunction with *SECON*), Reston, VA, September 25, 2006.

27. J. H. Reed, "Applications of Markov modeling to cognitive radio," presented at the *SASDCRT Conf.*, Naval Post Graduate School, Monterey, CA, September 12-13, 2006.

28. J. H. Reed, "Understanding the issues in software defined cognitive radios," seminar presented at Clemson University, SC, July 21, 2006.

29. J. H. Reed, "Understanding the issues in software defined cognitive radios," seminar presented at Kyung Hee University, Korea, June 12, 2006.

30. J. H. Reed, "Open architecture bridging the gap in emergency communications," guest speaker at the *International Wireless Communications Expo – IWCE Conf. Tektronix Symposium,* Las Vegas, NV, May 19, 2006.

31. J. H. Reed, "An introduction to cognitive radio and some research trends in cognitive radios," talk presented at *ETRI Cognitive Radio Workshop*, Seoul, Korea, April 2006.

32. J. H. Reed, S. Srikanteswara, and J. A. Neel, "Design choices for software radios," DVD tutorial. Available: http://sdrforum.org/store.html

33. Presentation titled "Software radio: The key for enabling 4G wireless networks," at the *International Forum - 4th Generation Mobile Commun.*, Centre for Telecommunications Research, May 2003.

34. J. H. Reed, "Key challenges in the design on software radios," workshop presented at *IDGA Software Radio Conf.*, Alexandria, Va., February 23, 2004.

35. J. H. Reed, "Issues in software radios," presented at Microsoft, Seattle, WA, March 3, 2003.

36. J. H. Reed, "Wireless convergence paradox," presented at *Samsung Telecom Forum*, Seoul, Korea, March 16-23, 2003.

37. W. H. Tranter, J. H. Reed, D. S. Ha, D. McKinstry, R. M. Buehrer, and J. Hicks, "High capacity communications using overloaded array," presented at *COMMTEC*, Chantilly, VA, September 16-20, 2002.

38. R. M. Buehrer and J. H. Reed, "Robust ad-hoc, short-range wireless networks for tracking and monitoring devices," presented to the Marine Corp., April 2002.

39. J. H. Reed, "Overloaded array processing with spatially reduced search joint detection," presented at the Dresden University of Technology, September 24, 2001.

40. J. H. Reed, Invited lecture series to several Korean companies, compliments of Samsung Advanced Institute of Technologies. The list of companies included: Samsung, LGIC, and ETRI. Spring 2000.

41. J. H. Reed, "The future of wireless," invited talk, Atlantic City, NJ, November 15, 1999.

42. J. H. Reed, "Software radios," *Motorola Futures Forum*, invited talk to corporate strategists, Pheonix, AZ, November 8, 1999.

43. P. Robert and J. H. Reed, "Digital video transmissions in a wireless system," *9th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

44. M. Hosemann and J. H. Reed, "Synchronization techniques for spread spectrum signals," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

45. S. Srikanteswara and J. H. Reed, "Development of a software radio architecture using reconfigurable computing," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

46. J. Hicks, P. Roy, J. Tilki, L. Beex, J. H. Reed, and W. Farley, "Simulation tool for speech recognition over wireless," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

47. R. Ertel and J. H. Reed, "Optimum SINR antenna array performance analysis," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

48. R. Banerjee, B. D. Woerner and J. H. Reed, "Case studies in software radios," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

49. P. M. Robert, A. M. Darwish, and J. H. Reed, "Fast bit error generation for the simulation of MPEG-2 transmissions in wireless systems," *IEEE Wireless Commun. Networking Conf.*, September 21-24, 1999. (Invited paper; proceedings on CD Rom.)

50. J. H. Reed and S. Srikanteswara, "Software radio architecture for a reconfigurable computing platform," *IEEE Commun. Theory Workshop*, Aptos, CA, May 23-26, 1999.

51. R. Ertel , Z. Hu and J. H. Reed, "Antenna array vector channel modeling and data collection system," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

52. P. M. Robert and J. H. Reed, "Digital video transmissions in a wireless system," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

53. S. Swanchara, S. Srikanteswara, P. Athanas, and J. H. Reed, "Implementation of a multiuser receiver on a recongifugurable computing platform," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

54. Maheshware, et al., "Reconfigurable software radio," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

55. K. Phillips and J. H. Reed, "PDF estimation," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

56. N. Mangalvedhe and J. H. Reed, "Performane of reduced complexity algorithms in adaptive CDMA receivers," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

57. R. Mostafa and J. H. Reed, "Study of smart antenna as an interference rejection technique for the handset," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

58. N. Mangalvedhe and J. H. Reed, "Adapative receivers for multi-rate DS-CDMA systems," *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

59. J. H. Reed and B. D. Woerner, "Analog to digital conversion and digital signal synthesis for software radios," half-day tutorial presented at the *IEEE 9th International Symposium*

Personal, Indoor, Mobile Radio Commun., Boston, MA, September 13-16, 1998. (Invited tutorial.)

60. J. H. Reed, "The software radio: Modern radio engineering," Dresden University of Technology Guest Lecture, Dresden, Germany, November 25, 1997.

61. J. H. Reed, "Adaptive antenna arrays," Dresden University of Technology Guest Lecture, Dresden, Germany, November 26, 1997.

62. J. H. Reed, "Overview of fundamental wireless systems in today's telecommunications technology," *46th Annual International Wire Cable Symposium*, Philadelphia, PA, November 17-20, 1997. (Invited tutorial.)

63. J. H. Reed and R. D. James, "Position location: Overview and business opportunities," *Wireless Opportunities Workshop*, Roanoke, VA, October 22-23, 1997.

64. R. Ertel and J. H. Reed, "Geometrically based spatial channel models," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

65. A. Hannan and J. H. Reed, "GloMo radio API (application program interface," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

66. S. Swanchara, J. H. Reed, and P. Athanas, "Design and implementation of the GloMo multiuser receiver on a reconfigurable computing platform," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

67. N. D. Tripathi, J. H. Reed, and H. VanLandingham, "High performance handoff algorithms using fuzzy logic and neural networks," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

68. D. Breslin and J. H. Reed, "Multi-sensor testbed hardware development at the mobile and portable radio resesarch group," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

69. N. Mangalvedhe and J. H. Reed, "Blind CDMA interference rejection in multipath channels," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

70. K. Phillips, J. Laster, and J. H. Reed "Adaptive signal processing by bit error rate (BER) estimation," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

71. T. S. Rappaport, J. H. Reed, and T. E. Biedka, "Position location & E-911: Techniques for wireless systems," *IEEE International Conf. Universal Pers. Commun.*, Cambridge, MA, October 1, 1996. (Invited tutorial.)

72. N. Tripathi and J. H. Reed, "DSP implementation of communications systems: An NSF sponsored curriculum development initiative," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

73. B. Fox, G. Aliftiras, I. Howitt, J. H. Reed, and B. D. Woerner, "Flexible hardware architectures for multimode wireless handsets," *Sixth 6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

74. P. Petrus and J. H. Reed, "Geometrically based statistical single bounce macrocell channel model for mobile environments," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session; also in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, & Wireless Position Location*, 1998, pp. 483-487.)

75. GloMo team, "GloMo adaptive antenna array research," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

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77. J. D. Laster and J. H. Reed, "Improved GMSK demodulation using non-coherent receiver diversity," *Sixth 6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

78. K. Khan, J. H. Reed,and I Howitt, "Interference mitigation in AMPS/NAMPS and CMP using artificial neural networks," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

79. N. Tripathi, J. H. Reed, and H. VanLandingham, "Neural net & fuzzy logic approaches to handoffs in cellular systems," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

80. K. Saldanha and J. H. Reed, "Performance evaluation of an AMPS digital base station with automatic gain control," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

81. R. He and J. H. Reed, "System capacity improvement by ysing DSP interference rejection techniques," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

82. B. D. Woerner, T. S. Rappaport, and J. H. Reed, "Improved spectral efficiency for CDMA systems," *Wireless Technology Conf. Exposition Proceedings*, Stamford, CT, September 1995.

83. P. Petrus and J. H. Reed, "New blind multichannel filtering techniques," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

84. N. Zecevic and J. H. Reed, "Comparative study of adaptive CDMA interference rejection techniques," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

85. M. Majmundar and J. H. Reed, "Interference rejection for IS-54," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

86. D. Bailey and J. H. Reed, "MPRG: Signal processing and communications laboratory," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

87. R. He and J. H. Reed, "Co-channel interference for AMPS and NAMPS signals," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

88. N. Mangalvedhe and J. H. Reed, "An Eigenstructure technique for soft synchronization of DSSS signals," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

89. M. Welborn and J. H. Reed, "Interference rejection using model-based spectral estimation," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

90. A. Amanna, R. James, and J. H. Reed, "Communications on the smart road," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

91. F. Dominique and J. H. Reed, "Development of a frequency hopping system for the 902-928 MHz ISM band," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

92. S. Elson and J. H. Reed, "Modeling CDPD," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.).

93. P. Petrus, F. Dominique, and J. H. Reed, "Spectral redundancy exploitation in narrowband interference rejection for a PN-BPSK system," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

94. F. Cheng and J. H. Reed, "Dynamic range enhancement techniques for RF and fiber optic interface," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

95. P. Petrus and J. H. Reed, " Blind adaptive arrays for mobile communications," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

96. R. He and J. H. Reed, "Spectral correlation of AMPS signals with applications to interference Rrejection," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

97. R. Zheng and J. H. Reed, "System modeling and interference rejection for spread spectrum CDMA automatic vehicle monitoring systems," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

98. N. Mangalvedhe and J. H. Reed, "An eigenstructure technique for soft spread spectrum synchronization," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

99. R. Holley and J. H. Reed, "Time-dependent filters For CDMA interference rejection," *3rd Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1993. (Poster session.)

Technical Reports:

1. Y. Zhao, "Enabling cognitive radios through radio environment maps," MPRG-TR-07- Ph.D. dissertation, May 2007.

2. R. Menon and J. H. Reed, "Interference avoidance based underlay techniques for dynamic spectrum sharing," MPRG-TR-07-, Ph.D. dissertation, April 2007.

3. J.-H. Kim and J. H. Reed, "On the impact of MIMO implementations on cellular networks: An analytical Aapproach from a system perspective," MPRG-TR-07-, Ph.D. dissertation, March 2007.

4. R. Chembil Palat and J. H. Reed, "Performance analysis of cooperative communications for wireless networks," MPRG-TR-06-, Ph.D. dissertation, December 2006.

5. J. O. Neel and J. H. Reed, "Analysis and design of cognitive radio networks and distributed radio resources management in algorithms," MPRG-TR-06-14, Ph.D. Dissertation, September 2006.

6. C. R. Anderson and J. H. Reed, "A software defined ultra wideband transceiver testbed for communications, ranging, and imaging," MPRG-TR-06-13, Ph.D. dissertation, September 2006.

7. C. R. Anderson, S. Venkatesh, D. Agarwal, R. Michael Buehrer, P. Athanas, and J. H. Reed, "Time interleaved sampling of impulse ultra wideband signals: Design challenges, analysis, and results," MPRG-TR-06-12, technical report, August 2006.

8. J.-H. Kim and J. H. Reed, "Efficacy of transmit smart antenna at mobile station in cellular networks," MPRG-TR-06-09, Ph.D. preliminary, May 2006.

9. J. A. DePriest and J. H. Reed, "A practical approach to rapid prototyping of SCA waveforms," MPRG-TR-06-06, M.S. thesis, April 2006.

10. B. M. Donlan, R. M. Buehrer, and J. H. Reed, "Ultra-wideband narrowband interference cancellation and channel modeling for communications," MPRG-TR-05-02, M.S. thesis, January 2005.

11. S. Vasudevan and J. H. Reed, "A simulator for analyzing the throughput of IEEE 802.11b wireless LAN systems," MPRG-TR-05-01, M.S. thesis, January 2005.

12. A. M. Hebbar and J. H. Reed, "Empirical approach for rate selection in MIMO OFDM," MPRG-TR-04-11, M.S. thesis, December 2004.

13. C. R. Anderson, A. M. Orndorff, R. M. Buehrer, and J. H. Reed, "An introduction and overview of an impulse-radio ultrawideband communication system design," MPRG_TR-04-07, technical report, May 2004.

14. J. Hicks and J. H. Reed, "Novel approaches to overloaded array processing," MPRG-TR-03-19, Ph.D. dissertation, August 2003.

15. R. Mostafa and J. H. Reed, "Feasibility of smart antennas for the small wireless terminals," MPRG-TR-03-12, Ph.D. dissertation, April 2003.

16. S. Krishnamoorthya and J. H. Reed, "Interference measurements and throughput analysis for 2.4 GHz wireless devices in hospital environments," MPRG-TR-03-10, M.S. thesis, April 2003.

17. P. M. Robert and J. H. Reed, "Reduction in coexistent WLAN interference through statistical traffic management, MPRG-TR-03-09, Ph.D. dissertation, April 2003.

18. W. G. Newhall and J. H. Reed, “Radio channel measurements and modeling for smart antenna array systems using a software radio receiver,” MPRG-TR-03-08, Ph.D. dissertation, April 2003.

19. Y. Ahmed and J. H. Reed, “A model-based approach to demodulation of co-channel MSK signals,” MPRG-TR-02-24, M.S. thesis, December 2002.

20. R. Chembil Palat and J. H. Reed, “VT-STAR design and implementation of a test bed space-time block coding and MOMI channel measurements,” MPRG-TR-02-19, M.S. thesis, October 2002.

21. W. Newhall and J. H. Reed, “Radio channel measurements, modeling, and characterization for antenna array Ssystems,” MPRG-TR-02-16, Ph.D. preliminary, August 2002.

22. B.-L. Cheung and J. H. Reed, “Simulation of adaptive array algorithms for OFDM and adaptive vector OFDM systems,” MPRG-TR-02-15, M.S. thesis, September 2002.

23. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report #19, MPRG-TR-02-13, technical report, April 2002.

24. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 17, MPRG-TR-02-05, technical report, January 2002.

25. S. Marikar, L. DaSilva, and J. H. Reed, “Resource management in 3G systems employing smart antennas,” MPRG-TR-02-04, M.S. thesis, January 2002.

26. P. M. Robert and J. H. Reed, “Reduction in coexistent WLAN interference through statistical traffic management,” MPRG-TR-02-01, Ph.D. preliminary, August 2001.

27. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 16, MPRG-TR-01-17, technical report, October 2001.

28. M. Soni, P. Athanas, and J. H. Reed, “Computing engine for reconfigurable software radio,” MPRG-TR-01-15, M.S. thesis, October 2001.

29. T. E. Biedka and J. H. Reed, “Analysis and development of blind adaptive beamforming algorithms,” MPRG-TR-01-14, Ph.D. dissertation, August 2001.

30. R. Gozali, R. Mostafa, P. M. Robert, R. Chembil Palat, W. Newhall, B. D. Woerner, and J. H. Reed, “Design process of the VT-STAR multiple-input multiple-output (MIMO) test bed,” MPRG-TR-01-12, technical report. August 2001.

31. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 15, MPRG-TR-01-11, technical report, July 2001.

32. S. Srikanteswara and J. H. Reed, “Design and implementation of a soft radio architecture for reconfigurable platforms,” MPRG-TR-01-10, Ph.D. dissertation, July 2001.

33. R. Mostafa and J. H. Reed, “Feasibility of transmit smart antenna at the handset,” MPRG-TR-01-07, Ph,D. preliminary, December 2000.

34. J. Hicks and J. H. Reed, “Overloaded array processing with spatially reduced search joint detection,” MPRG-TR-00-08, M.S. thesis, May 2000.

35. T. Biedka and J. H. Reed, “A general framework for the analysis and development of blind adaptive algorithms,” MPRG-TR-OO-O5, Ph.D. preliminary, April 2000.

36. S. Srikanteswara and J. H. Reed, “Design and implementation of a soft radio architecture for reconfigurable platforms,” MPRG-TR-00-02, Ph.D. preliminary, November 1999.

37. R. B. Ertel and J. H. Reed, "Antenna array systems: Propagation and performance,” Ph.D. dissertation, July 1999.

38. N. R. Mangalvedhe and J. H. Reed, “Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems,” Ph.D. dissertation, July 1999.

39. K. Phillips and J. H. Reed, “Probability density function estimation for minimum bit error rate equalization,” MPRG-TR-99-04, M.S. thesis, May 1999.

40. Z. Hu and J. H. Reed, “Evaluation of joint AOA and DOA estimation algorithms using the antenna array systems,” MPRG-TR-99-02, M.S. thesis, December 1998.

41. R. B. Ertel and J. H. Reed, "Antenna array systems: Propagation and performance," MPRG-TR-98-12, Ph.D. preliminary, December 1998.

42. N. R. Mangalvedhe and J. H. Reed, "Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems," MPRG-TR-98-13, Ph.D. preliminary, December 1998.

43. P. M. Robert and J. H. Reed, "Simulation tool and metric for evaluating wireless digital video systems," MPRG-TR-98-11, M.S. thesis, September 1998.

44. S. F. Swanchara and J. H. Reed, “An FPGA-based multiuser receiver employing parallel interference cancellation,” MPRG-TR-98-06, M.S. thesis, July 1998.

45. N. Tripathi and J. H. Reed, “Generic handoff algorithms using fuzzy logic and neural networks,” Ph.D. dissertation, MPRG-TR-97-18, November 1997.

46. D. Breslin and J. H. Reed, “Adaptive antenna arrays applied to position location,” MPRG-TR-97-14, M.S. thesis, August 1997.

47. S. Nicoloso and J. H. Reed, “Investigation of carrier recovery techniques for PSK modulated signals in CDMA and multipath mobile environments,” MPRG-TR-97-11, M.S. Thesis, May 1997.

48. N. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive direction biased fuzzy handoff algorithm with unified handoff candidate selection criterion,” MPRG-TR-97-08, April 1997.

49. N. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive algorithm using neural encoded fuzzy logic system,” MPRG-TR-97-07, April 1997.

50. N. Tripathi, J. H. Reed, and H. VanLandingham, "A new class of fuzzy logic based adaptive handoff algorithms for enhanced cellular system performance," MPRG-TR-97-06, April 1997.

51. B. Fox and J. H. Reed, "Analysis and dynamic range enhancement of the analog-to-digital interface in multimode radio receivers," MPRG-TR-97-02, February 1997.

52. A. Alexander, S. Panchapakesan, D. Breslin, J. H. Reed, T. Pratt, and B. D. Woerner, "The feasibility of performing TDOA based position location on existing cellular infrastructures," MPRG-TR-96-37, December 20, 1996.

53. N. Tripathi and J. H. Reed, "Handoffs in cellular systems: A tutorial," MPRG-TR-96-35, November 1996.

54. N. Zecevic and J. H. Reed, "Interference rejection techniques for the mobile unit direct-sequence CDMA receiver," MPRG-TR-96-27, August 1996.

55. K. J. Saldanha and J. H. Reed, "Performance evaluation of DECT in different radio environments," MPRG -TR-96-28, August 1996.

56. R. He and J. H. Reed, "AMPS co-channel interference rejection techniques and their impact on system capacity," MPRG-TR-96-25, July 1996.

57. N. Zecevic and J. H. Reed, "Techniques and adaptation algorithms for direct sequence spread spectrum capacity," MPRG-TR-96-27, July 1996.

58. M. K. Khan, J. H. Reed, and I. Howitt, "Interference mitigation in AMPS/NAMPS and GSM using artificial neural networks," MPRG-TR-96-24, June 1996.

59. J. H. Reed, T. S. Rappaport, and B. D. Woerner, "What you should know before returning to school," *RF Design*, pp. 67-69, March 1996.

60. T. Biedka and J. H. Reed, "Direction finding methods for CDMA mobile wireless systems," MPRG-TR-96-20, June 1996.

61. Y. M. Vasavada and J. H. Reed, "Performance evaluation of a frequency modulated spread-spectrum system," MPRG-TR-96-13, February 1996.

62. M. V. Majmundar and J. H. Reed, "Adaptive single-user receivers for direct sequence CDMA systems," MPRG-TR-96-12, January 1996.

63. R. He and J. H. Reed, "Co-channel interference rejection techniques for AMPS signals using spectral correlation characteristics," MPRG-TR-96-11, January 1996.

64. J. S. Elson and J. H. Reed, "Simulation and performance analysis of cellular digital packet data," MPRG-TR-96-08, February 1996.

65. J. D. Laster and J. H. Reed, "Improved GMSK demodulation emphasizing single channel interference rejection techniques," MPRG-TR-96-05, February 1996.

66. M. Welborn and J. H. Reed, "Co-channel interference rejection using model-based demodulator" MPRG-TR-96-04, January 1996.

67. F. Dominique and J. H. Reed, "Design and development of a frequency hopper based on the DECT system for the 902-928 MHz ISM band," MPRG-TR-96-02, January 1996.

68. P. Athanas, I. Howitt, T. S. Rappaport, J. H. Reed, and B. D. Woerner, "A high capacity adaptive wireless receiver implemented with a reconfigurable computer architecture," MPRG-TR-18, November 1995.

69. N. Mangalvedhe and J. H. Reed, "An eigenstructure technique for direct sequence spread spectrum synchronization," MPRG-TR-95-04, April 1995.

70. Y. M. Kim, N. Mangalvedhe, B. D. Woerner, and J. H. Reed, "Development of a low power high data rate spread-spectrum modem," MPRG-PPR-95-01, February 1995.

71. Y. M. Kim, N. R. Mangalvedhe, B. D. Woerner, and J. H. Reed, "Development of a low power high data rate spread-spectrum modem," MPRG-PPR-95-02, June 1995.

72. P. Petrus and J. H. Reed, "Blind adaptive antenna arrays for mobile communications," MPRG-TR-95-01, December 1994.

73. S. Yao and J. H. Reed, "Differential detection of GMSK signals," MPRG-TR-94-27, October 1994.

74. R. Zheng, J. Tsai, R. Cameron, L. Beisgen, B. D. Woerner, and J. H. Reed, "Capacity and interference resistance of spread-spectrum automatic vehicle monitoring systems in the 902-928 MHz ISM Band," MPRG-TR-94-26, final report to Southwestern Bell Mobile Systems, October 1994.

75. F.-S. Cheng and J. H. Reed, "A new approach to dynamic range enhancement," MPRG-TR-94-25, October 1994.

76. R. S. Zheng and J. H. Reed, "Channel modeling and interference rejection for CDMA automatic vehicle monitoring systems," MPRG-TR-94-21, November 1994.

77. R. He and J. H. Reed, "AMPS interference rejection: Blind time-dependent adaptive filtering - Volume I," final report to ARGO Systems Inc., MPRG-TR-94-19, July 1994.

78. T. H. Qazi and J. H. Reed, "Model-based demodulation of FM signals - Volume II," MPRG-TR-94-17, final report to ARGO Systems, August 1994.

79. M. Subramanian and J. H. Reed, "Noncoherent spread-spectrum communication systems," MPRG-TR-94-14, August 1994.

80. F. Cheng, A. Kelkar, I. Jacobs, and J. H. Reed, "Performance evaluation for the dynamic range enhancement technique (DRET)," MPRG-TR-94-10, final report to Southwestern Bell Technology Resources, September 1994.

81. V. Aue and J. H. Reed, "Optimum linear single user detection in direct-sequence spread-spectrum multiple access systems," MPRG-TR-94-03, March 1994.

82. R. Holley and J. H. Reed, "Time dependent adaptive filters for interference cancellation in CDMA systems," MPRG-TR-93-15, September 1993.

Other Papers & Reports:

1. P. M. Robert and J. H. Reed, "Va. Tech finds soft radio's missing link," *EE Times*, August 2004.

2. J. H. Reed, T. C. Hsia, and H. Etemad, "Differential demodulation of BPSK using time dependent adaptive filtering," final report to California MICRO Program, 1992.

3. J. H. Reed, "Adaptive filters and their application to interference rejection," *Defense Electronics*, pp. 85-86 and 89-90, May 1989.

4. W. Gardner, B. G. Agee, W. A. Brown, C. K. Chen, J. H. Reed, and R. S. Roberts, "A comparison of Fourier transformation and model fitting methods of spectral analysis," Signal and Image Processing Lab Report No. SIPL-86-4, Department of Electrical and Computer Engineering, University of California, Davis, 1986. (Also in *Statistical Spectral Analysis — A Non Probabilistic Theory*, Prentice-Hall.)

Selected Corporate Report Topics:

- A DSP-Based Receiver for the New North American Digital Cellular Standard
- Spread Spectrum Detection Techniques
- Cyclic Spectral Analysis of Modulated Signals
- Projection of Future High-Volume Digital Communication Systems
- A High Speed Digital Filter for Sample Rate Conversion
- A Least-Squares System Identification Method
- Cyclic Adaptive Filtering for Interference Rejection
- Implementation Issues of Adaptive Interference Rejection Techniques
- Investigation of Modern Spectral Analysis Techniques
- The Performance of Time-Dependent Adaptive Filtering of Real Data
- A Maximum-Likelihood Estimator for Tracking and Detecting Frequency Hopping Signals
- Digital Signal Processing Algorithms for Squelch Control
- A Low-Cost Whitening Filter for Jammer Applications
- Time-Dependent Single Channel and Multi-Channel Interference Rejection Algorithms

Section V. Public Service/Outreach

Industrial Affiliate/Outside Agency Contacts:

Companies and Government Agencies visited in 2009 - 2010 to promote Wireless@ VT and the Hume Center:

Booz Allan Hamilton
DARPA
Army Research Lab
ZETA
SAIC
DRT
Laboratory of Telecommunications Science
John Hopkins Applied Physics Lab
NRO
NSA
CRT
Defense Spectrum Office
NIST
NRL
Northrup Grumman
ISI
RINCOM
CERDEC
Award Solution
IDA
Motorola
NSA
MA-COMM
Intel
NSF
FCC
FBI
Samsung
Aerospace Corporation
CIA
US Army
Thales Communications
Textronix
ONR
SPAWAR
ATT
Ventura Solutions
Syracuse Research Corp

Funding Agency Reviewer:

NSF
University of California, MICRO
Kansas 2000
Qtar Science Foundation
ARO
Canadian Foundation for Innovation

Sponsored Visiting Researchers:

Ahmed Darwish from Cairo University, June-September 1999
Yeongjee Chung from Korea, January-August 1999
Shinichi Miyamoto from Kobe, Japan, April 2001-March 2002
Young-Soo Kim from Seoul, Korea, February 2002-February 2003
Friedrich Jondral from Karlsruhe, Germany, April-June 2004
Francisco Portelinha from Brazil, October 2004-February 2006
Seuck Ho Won from Korea, February 2005-January 2006
Duk Kyu Park from Seoul South Korea, January 2007-February 2008
Marojevic Vuk from Spain, September 2007-January 2008
Francisco Martins Portelinha from Brazil, February 2008-March 2008
Jeong Ho Kim from South Korea, July 2008 – February 2010
Stefan Werner Nagel from Germany, August 2009 - October 2009

Conference Organization & Technical Reviewering:

Organizing Committee for Globecom 2010
Technical Program Committee for IEEE Dyspan 2009/2010
Technical Program Committee for Globecomm 2009

Technical Program Committee for VTC 2009
Technical Program Committee for COMCAS 2009 (and session chair)
Associate Editor for Proceedings of the IEEE, Issue on Cognitive Radio, April & May 2009
Associate Editor for IEEE Journal on Select Area of Communications, Issue on Cognitive Radio
Technical Program Committee for IEEE Conference on Communications
Technical Program Committee for CrownCom
Reviewer

- *IEEE Transactions on Antennas and Propagation*
- *IEEE Transactions on Wireless Communications*
- *IEEE Transactions on Communications*
- *IEEE Transactions on Signal Processing*
- *IEEE Transactions on Aerospace and Electronics Systems*
- *IEEE Transactions on Selected Areas of Communications*
- *IEEE Signal Processing Letters*
- *IEEE Communications Magazine*
- *IEEE Communications Letters*
- *International Journal of Electronics*

Session Chair for the SDR Forum 2007, Denver, CO, November 5 – 9, 2007
Advisory Board, *IEEE International Conf. Ultrawideband (ICU)*, September 2005.
Moderator for the paper session "Ultrawideband Design Approaches," at the *Communications Design Conf.*, March - April 2004.
Moderator for the panel, "UWB Panel on Communication Systems Design," at the *Communications System Design Conf.*, October 2003.
Chair of session titled, "Mobile Computing and Software Defined Radios," at the *International Conf. Engineering Reconfigurable Systems Algorithms (ERSA)*, June 2003.
Co-technical program chairman for the *SDR Forum Conf.*, November 2002.
General Chair for the *UWBST Conf.*, November 2003.
Technical program chairman for the *SDR Forum/MPRG Workshop Smart Antennas*, June 2003.

Federal & State:

National Science Foundation workshop co-organizer, *Enhancing Access to the Radio Spectrum*, August, 2010. Goal was to develop a major research program to support spectrum research for the National Broadband Plan. Participants include Secretary of Commerce, a Commissioner of the FCC, interim head of NSF, multiple NSF Division Directors, Whitehouse and Capitol Hill staffers.

US Dept. of Commerce Committee on EARS Regulations 2008-2009. A Federal Advisory Committee Appointed by the Secretary of Commerce To examine EARS Regulations. 2009. *Note current EARS regulations currently represent a major challenge to US industry and academia for engaging international personnel in research and this committee addressed this challenge.* 2007.

Co-Leader for the SDR Forum and Object Management Group of Smart Antenna API standardization efforts 2008-2009

Co-Leader for NSF workshop on SDR held in Ireland on May 12 – 16, 2008.

Virginia Broadband Task Force (headed by now Senator Warner and US CTO Anish Chopra) to examine steps for bridging the digital divide.

DARPA panel member to identify and create new programs for DARPA to support NSA. This activity is expected to result in $60M – $80M in new DARPA programs. 2007

Workshop help DARPA define a new program in bio-mimesis, the imitation of living organisms through electronics and mechanics.

Assisted the Army Research Office in developing their five year research plan for communications

Informal advisor to OSTP, Senators Snowe and Warners on spectrum issues.

University Professional Service Current & Past:

Director Wireless @ Virginia Tech
Interim Director, Ted and Karyn Hume Center
Participation within the Center for Wireless Telecommunications (CWT)
Department Computing Committee
Faculty Advisor to the Honor System
Faculty Advisory Committee, Information Technology for VT
EE Graduate Administrative Committee (Grad AdCom)
Communications Area Committee
US Student Recruitment Strategy Task Force
Course supervisor of ECPE 5674 and ECPE 4654
ECE Department Head Search Committee
ECE Executive Committee
ECE Resource Committee
Deputy Director, MPRG
ECE Recruiting Committee

Section VI. Industrial Experience

Industrial Employment:

Cognitive Radio Technology, LLC. CTO and co-founder, 2007- Present

Co-founded Dot Mobile, Inc. March 2000-2001
(Company specializes in mobile data applications including wireless-internet based applications.)

Past Clients

ACM Systems	Grass Valley Group
Analog Devices	BRTRC
DIGCOM	E-Systems
F&S	General Dynamics
Gray Cary	Harris Broadband
Honeywell	HRL

IWT	Jones Day
NORCOMM	SAIC
Labarge	IDA
SRC	Weil
Samsung	MITRE
Shafer	SCA Technica
IIT	Navsys
US Navy	Tantivy

Founded Reed Engineering, March 1986 – Present
(Company performs consulting, expert witnessing and training in wireless communications and signal processing.)

Member, Technical Staff Signal Science, Inc., Santa Clara, CA, 1980-1985
Areas of Specialization:

- Spread spectrum detection
- Foreign technology analysis
- Computer systems administration

Past and Current Advisory Board Positions:

TechContinuum
Samsung Telecommunications
Spyrock
Totus Lighting
Airbee
FAWNA
Wayve Tech

Selected past industry projects:

- Expert Witness Wireless Email
- Software Architecture for Radios
- Company acquisition evaluation
- Expert witness in wireless location systems (multiple times)
- Evaluation of a wireless high-speed internet access system
- Evaluation of wireless/signal processing companies for acquisition
- Tutorials on software radio issues
- Tutorials on trends in wireless communications
- Adaptive interference rejection techniques
- Spread spectrum signal detection
- Expert witness for wireless power sources
- Study Panelist for NSA/DARPA programs via Schafer Corp.
- Advising on Trends in Communications: SAIC
- Provide Survey of Low Power Communications Trends: Mitre Corporation

Nishith D. Tripathi, Ph. D.
419 Stone Bridge Circle, Allen, TX 75013
Tel.: 214-477-3516 and E-mail: ntripathi77@gmail.com

AREAS OF EXPERTISE

LTE (E-UTRAN and EPC), LTE-Advanced, WiMAX, 1xEV-DO (Rev. 0 and Rev. A), UMTS R99, HSDPA, HSUPA, HSPA+, CDMA2000 1xRTT, IS-95, CDMA, OFDM, OFDMA, Advanced Antenna Technologies, IP-related Technologies, IMS

PUBLICATIONS

- Author of an upcoming **book** (with Jeffrey H. Reed), "Cellular Communications: A Comprehensive and Practical Guide," ***Accepted for Publication by IEEE/Wiley***, 2011. (**Book Contents**: Introduction to Cellular Communications, Elements of a Digital Communication System, Radio Propagation, IP Fundamentals, GSM, GPRS, EDGE, IS-95, CDMA2000 1xRTT, R99 UMTS/WCDMA, 1xEV-DO Rev. 0, HSDPA, 1xEV-DO Rev. A, HSUPA, HSPA+, IMS, Emerging 4G Technologies)
- Author of a **book** (with Jeffrey H. Reed and Hugh F. VanLandingham), "Radio Resource Management in Cellular Systems," Kluwer Academic Publishers, 2001.
- Contributor (With Jeffrey H. Reed) to the article, "Technical Challenges in Applying Network Neutrality Regulations to Wireless Systems," To appear in the book titled "The Net Neutrality Debate," 2011.
- Author of one chapter in the book, "Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications," Editor- Peter Stavroulakis, Springer, April 2004.

EXPERIENCE

AWARD SOLUTIONS *March '04 to Present*

Principal Consultant

- Successfully launched a new program to ensure and develop SME (Subject Matter Expert) expertise in the areas of LTE RAN and Ethernet-based Backhaul. Developed processes and plans to facilitate SME certification. Devised expertise development plans, on-line tests, and defense tests. Directed the oral defense meetings for the final stage of SME certification.
- Managed and led SMEs for following course development projects: LTE Bootcamp- Phase II (**Topics**: End-to-end Data Sessions in LTE-EPC, PCC: QoS and Charging Architecture for LTE, Voice over LTE (VoLTE) using IMS, Voice services using CSFB and SRVCC, LTE and eHRPD Interworking, LTE and GSM/UMTS interworking, and LTE-Advanced), and LTE Radio Network Planning and Design.
- Mentored SMEs to prepare them to teach technologies such as LTE, WiMAX, OFDM, and Advanced Antennas.
- Developed courses on LTE-Advanced and TD-LTE.
- Developed two sessions, TD-LTE and Self Organizing Network (SON), as part of LTE Bootcamp- Phase II for an infrastructure vendor.
- Enhanced the LTE Radio Network Planning and Design course to reflect configurations of commercial deployments using LTE log-files and to adhere to customer-specific RF design guidelines.
- Continued to teach a variety of LTE and HSPA+ courses (e.g., VoIP, IMS, and IPv6 for LTE and HSPA+ Signaling) at new and existing clients.
- Delivered several web-based sessions of LTE Bootcamp- Phase II.

Lead SME

- Taught *first-time offerings* of courses at various clients to acquire new training business.
- Managed and guided SMEs for timely and quality-controlled completion of following course development projects: LTE/1xEV-DO Interworking, EPC Overview, HSPA+ Overview, Fundamentals of RF Engineering, IP Convergence Overview, and Advanced Antenna Techniques.

- Devised and implemented strategies to maximize the quality of project deliverables and to accelerate the completion of the deliverables.

SME- Course Development

- Developed an in-depth LTE Bootcamp Series for an infrastructure vendor (**Topics**: EPS Network Architecture, OFDMA/SC-FDMA, Radio Channels, System Acquisition & Call Setup, DL & UL Traffic Operations, Handover, and Antenna Techniques).
- Developed numerous instructor-led and web-based training courses by working in a team environment (**Examples**: Interworking of LTE with 1xEV-DO & 1xRTT, LTE Air Interface, WiMAX Essentials, WiMAX Network Planning, UMB, 1xEV-DO, HSUPA, Multiple Antenna Techniques, and IP Convergence).
- **Example Course Contents**: Network architecture, air interface features, DL & UL data transmission, call setup, handover/handoff, resource management, and interworking.
- Designed outlines for several new courses.

Senior Consultant- Training

- Taught *in-person* and *web-based* (via WebEx and LiveMeeting) courses at major chip-set manufacturers, infrastructure & device vendors, service operators, and test-tool vendors.
- Delivered an in-depth LTE bootcamp multiple times for a major LTE infrastructure vendor.
- **Area Expertise**: LTE Radio Network Planning & Design (including Certification), Interworking of LTE with (1xEV-DO, 1xRTT, UMTS, and GERAN), LTE Protocols & Signaling, LTE Air Interface, WiMAX Networks and Signaling, 1xEV-DO Optimization, 1xEV-DO Rev. 0 and Rev. A, IP Fundamentals, HSDPA/HSUPA/HSPA+, UMTS R4/R5 Core Networks, UMTS Network Planning and Design
- Strived to make the training experience full of *relevant* knowledge and to maximize the value of training to students.

HUAWEI TECHNOLOGIES *October '01 to March '04*

Product Manager and Senior Systems Engineer

- Worked with engineers to resolve numerous **field trial issues** for **CDMA2000** systems.
- Defined test procedures for various features to evaluate performance of the CDMA2000 product.
- Designed advanced RL MAC and Power Control algorithms for a 1xEV-DO System.
- Designed various high-performance radio resource management (RRM) algorithms for the **CDMA2000** base station and base station controller. Major designed features include adaptive forward link and reverse link call admission control algorithms, dynamic F-SCH rate and burst duration assignment algorithms, R-SCH rate assignment algorithm, F-SCH burst extension and termination mechanisms, schedulers, forward link and reverse link overload detection and control algorithms, SCH soft handoff algorithm, F-SCH power control parameter assignment mechanism, adaptive radio configuration assignment algorithm, load balancing algorithm, and cell-breathing algorithm.
- Worked on the design of an RRM simulator to evaluate the performance of call admission control, load control, and scheduling algorithms for a **CDMA2000** system.
- Designed system level and network level simulators to evaluate the capacity gain of the smart antenna-based **UMTS** systems employing multiple beams.
- Reviewed **UMTS** RRM design and proposed enhancements related to call admission control, cell breathing, load balancing, soft capacity control, potential user control, and AMR control.
- Educated engineers through presentations to facilitate development of the **1xEV-DO** product.
- Led a team of engineers to define a comprehensive **simulation tool-set** consisting of link level simulator, system level simulator, and network level simulator to evaluate performance of CDMA systems including **IS-95**, **IS-2000**, **1xEV-DO**, **1xEV-DV**, and **UMTS**.
- Managed a group of engineers, prepared project plans, and established efficient processes to meet the requirements of the **CDMA2000** BSC product line.

NORTEL NETWORKS *September '97 to September '01*

Senior Engineer

Radio Resource Management, July '99 to Sept. '01

- Developed a comprehensive RRM simulator that models data traffic and major features of the MAC layer and physical layer. Analyzed various aspects of the RRM for several test cases. The performance results such as capacity and throughput were used in educating the service providers on the RRM for IS-2000 systems.
- Proposed a generic call admission control algorithm and filed a patent with the U.S. Patent Office.

Management of Supplemental Channels, June '00 to Sept. '01

- Designed and analyzed supplemental channel management for enhanced data performance and filed a patent with the U.S. Patent Office.

Data Traffic Modeling, Jan. '99 to Sept. '01

- Prepared a common framework for data traffic models for analysis of systems carrying data (e.g., 1xRTT and UMTS). Types of analysis include RF capacity, end-to-end performance, and provisioning. The data models for telnet, WWW, ftp, e-mail, FAX, and WAP services are considered.

Multi-Carrier Traffic Allocation, June '99 to Sept. '01

- Provided MCTA capacity improvements (compared to non-MCTA systems) that proved to be identical to the ones observed during the field-testing. Developed a method to estimate the MCTA capacity using the field data. This method was used in estimating MCTA capacity gains by RF engineering teams.

SmartRate and Related Vocoder Designs (e.g., SMV), June '99 to Sept. '01

- Provided estimates of SmartRate capacity improvements that were found to be close to the observed capacity gains in the field tests.

CDMA Based Fixed Wireless Access Systems, Sept. '97 to Dec. '98

- **Capacity Estimates**. Determined the system capacity for a variety of configurations using an IS-95 based simulator. These configurations include different rates such as 9.6 kbps and 13 kbps, different deployment scenarios such as 2-tier embedded sector and border sector, and different diversity techniques such as switch antenna diversity and phase sweeping transmit diversity. These capacity estimates were used for various project bids. The simulator utilizes propagation channel models extracted from the actual field measurements.
- **Handoff and Power Control Algorithms**. Analyzed existing handoff and power control mechanisms for fixed wireless systems and proposed new approaches.
- **Bridge between the Simulator and a Deployed System**. Developed a procedure to estimate the loading level for the simulator so that the capacity estimate from the simulator is close to the achieved capacity in real systems.
- **Switch Antenna Diversity Schemes**. Proposed three algorithms to exploit mobile switch antenna diversity. These schemes provide a low-cost solution that significantly enhances RF capacity.
- **Combined Overhead Power and Handoff Management**. Proposed a method of combined management of overhead channel power and handoff to improve capacity.

Educator

- Made presentations on topics such as data modeling, fixed wireless systems, and AI tools.
- Taught "Introduction to Wireless" class at Nortel.
- Prepared tutorials on the standards such as 1xRTT, 1xEV-DO, and UMTS.

VIRGINIA TECH *January '93 to August '97*

Research/Teaching Assistant, Mobile & Portable Radio Research Group (MPRG), Electrical Engineering

- Developed adaptive intelligent handoff algorithms to preserve and enhance the capacity and the Quality of Service of cellular systems.
- Helped *develop* and *teach* a new wireless communications course **(DSP Implementation of Communication Systems**) as part of an **NSF** sponsored curriculum innovations program. Implemented different subsystems of a communication system (e.g., a digital transmitter, a carrier recovery system, a code synchronizer, and a symbol timing recovery system) using the **Texas Instruments** TMS320C30 DSP development system.
- Refined the class material for undergraduate and graduate signal processing classes.
- Investigated different aspects involved in dual-mode adaptive reconfigurable receivers as part of a project sponsored by **Texas Instruments**.

PATENTS/DRAFTS (AUTHOR/CO-AUTHOR)

- Enhanced Power Control Algorithms for CDMA-Based Fixed Wireless Systems, Patent Number 6,587,442, Filed Date: October 28, 1999.
- Method and apparatus for managing a CDMA supplemental channel, Patent Number 6,862,268, Filed Date: December 29, 2000.
- Dynamic Power Partitioning Based Radio Resource Management Algorithm, Patent Disclosure No.: 11942RR, Filed Date: August 23, 2000.
- Switch Antenna Diversity Techniques at the Terminal to Enhance Capacity of CDMA Systems, Patent Disclosure No. RR2544, Filed Date: June 19, 1998.
- Adaptive Radio Configuration Assignment for a CDMA System, October 2003.
- Multi-carrier Load Balancing for Mixed Voice and Data Services, October 2003.
- Methodology for Hierarchical and Selective Overload Control on Forward and Reverse Links in a CDMA System, October 2003.
- A New Predictive Multi-user Scheduling Scheme for CDMA Systems, November 2003.
- A New Method for Solving ACK Compression Problem by Generating TCK ACKs based on RLP ACKs on the Reverse Link, October 2003.

ACTIVITIES

Member of **IEEE**. Reviewed research papers for the *IEEE Transactions on Vehicular Technology*, *IEE Electronics Letters* and the *IEEE Control Systems Magazine*.

EDUCATION

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY **Blacksburg, VA**
Ph.D., Wireless Communications, August 1997, Overall GPA: 3.8/4.0
Dissertation: Generic adaptive handoff algorithms using fuzzy logic and neural networks

M.S., Electrical Engineering, November 1994, Overall GPA: 3.8/4.0

GUJARAT UNIVERSITY **Ahmedabad, India**
B.S., Electrical Engineering, September 1992
Graduated among the top 2% of the class.