Public Safety Interoperable Communications and the 700 MHz D Block Proceeding

Testimony for FCC En Banc Hearing
Stagg Newman
Principal
Pisgah Comm Consulting
stagg@pisgahvu.com
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Chairman Martin, Commissioners Adelstein, Copps, McDowell, and Tate, thank you for inviting me to testify on the topic of building a nationwide, broadband interoperable public safety network. I am honored to provide my analysis of a topic I first worked on as Chief Technologist at the FCC in 1999 and then advocated and pursued as CTO of Frontline Wireless in 2007.

Pursuit of a Public Safety wireless broadband network is a very complex problem with many hard technical and operational choices to be made. These choices will **critically** affect the basic viability of the network and make a difference of billions of dollars in up-front capital expenses and on-going operating expenses, which are often overlooked, but perhaps even more important. The diversity of filings shows no consensus on these difficult choices; indeed there is a plethora of viewpoints. If there is one single point I could convey it is this: The FCC must lead an industry process to synthesize these diverse viewpoints so that the Commission, the Public Safety community, and the telecommunications industry can make the difficult choices needed for a successful rulemaking that leads to an working economic and technical solution. This path can make the US a global leader, not a laggard, in providing our first responders with the next generation wireless broadband network that they deserve.

To make these key choices, the FCC must first clearly define the priority problem(s) that must and can be solved in the upcoming 700 MHz rulemaking. I submit that priority one is building the broadband wireless network capabilities needed for first responders. The FCC should not be diverted from that focus by, for example, the "pipe dream" of creating a third wireless broadband alternative to wireline DSL and cable, which would take well in excess of 100 MHz of prime low frequency spectrum to be viable. (see Appendix A, Stagg Newman May 8, 2008 ex parte filing). And the FCC must recognize that to solve interoperability among many legacy narrowband mission-critical public safety voice networks and data networks is not a spectrum allocation problem, but a higher layer logical problem. This interoperability must be provided through the funding and building of gateways for today's legacy public safety networks. In this rulemaking, the Commission must focus first and foremost on interoperable capabilities for Public Safety broadband networking enabled by IP based applications over wireless and wired access, the platform for the future.

Turning to the focus of this en banc, the public safety interoperable broadband network, service and technical requirements critically affect the economic viability of any solution. The single biggest driver of capex and opex is cell sites, the number needed and the cost of each. The number of cell sites is driven by coverage and capacity requirements. Subtle changes in the requirements are critical in determining economic viability.

In addition to the geographic or population coverage requirement, more subtle technical factors that determine coverage requirements are:

- Type of subscriber handsets to be supported at the cell edge (e.g. vehicular with high-gain antenna versus small handheld)
- In-building or outdoor coverage
- % successful calls, in what % of local geography
- High-speed mobility, nomadic coverage, or stationary
- And the all-important minimum acceptable cell edge speed

To illustrate how critical these parameters are, consider a network design commissioned by Frontline Wireless for the state of North Carolina (see Appendix B). The network was designed to provide broadband services with the following key parameters

- a cell edge speed of 300 kbps downlink and 75 kbps uplink
- coverage footprint equivalent to the better of either
    - the current NC law enforcement narrowband (shared 10 kbps) data network (vehicular coverage to almost any place a sheriff's car can drive to 1.5 W roof mounted radio)

  or
    - the current commercial cellular footprint

In this scenario deep in-building coverage for law enforcement data applications would be provided by vehicular repeaters. These requirements are not necessarily the "right answer" but do illustrate the type of specific parameters that must be defined to understand network costs and performance. The network required 283 3-sector cell sites.

Now suppose the network was required support

- cell edge speed of 1.2 Mbps downlink and 512 kbps uplink
- same coverage area for law enforcement as above but for low-power handheld devices inside buildings

Then the network would need 2 to 4 times as many cell sites. At an upfront cost of $200,000 to $500,000 per tower, the up-front cost of the network in North Caroliina alone would increase well in excess $100 million, which translates into many billions of capex nationally. Moreover, each tower represents on-going, annual operating of $50,000 to $100,000. So a doubling of sites would mean an increase in annual expenses of tens of millions of dollars for the state of North Carolina alone. The Commission must understand such technical and economic facts in order to make the difficult choices.

Time does not permit illustrating the impact of service requirements on network capacity in detail. So for simplicity, consider the following three scenarios:

> The network must be designed to support typical bursty high-speed Internet applications for public safety to complement public safety's use of commercial cellular networks for day-to-day voice communications and narrowband trunked radio networks for mission critical voice
> The network must support the above *and* public safety's current voice traffic
> The network must also support the uplink of high definition quality video to large screen monitors

In the first case, my analysis showed there was enough capacity to support public safety operational and emergency needs and a viable commercial operation. In the second case, much less capacity is available for commercial operations and so much more revenue would be required from public safety to support the expensive network build. In the third scenario, all of the capacity in a cell sector representing on the order of $100,000 of capex, would be needed to support a single streaming video session, something that is clearly not economically viable.

Tackling the tough decisions related to technical and service requirement will be pointless if no companies step up to the task of building the public safety network capabilities. Therefore the Commission must understand the viability of different business or operating models_for public safety broadband networks. Should it be

1. a dedicated government network,
2. a partnership model as with the D Block,
3. or a priority service offered via a network of networks using wireless broadband access on advanced commercial networks?

The first approach could provide a network most tailored to the public safety community's needs, but such a dedicated network, according to Verizon, would cost the country at least XXX billions of dollars. The attempt at the second approach, of course, failed in the last auction but could be made to succeed if difficult choices are made so that the commercial sector sees a viable business opportunity and first responder agencies believe their needs will be met. The third approach, which is the approached used in for wireline broadband networking today, would most probably be the most cost-effective and provide the quickest solution in light of the advanced wireless networks that the industry will be building, but only if public safety perceives that their needs for reliability, security, and performance will be met.

The commission should also analyze whether the PSBL should be paired with the D Block. While most agree that 20 MHz or more of spectrum capacity is desirable to handle peak demands of a public/private broadband network, it is absolutely not the case that the spectrum needs to be "adjacent". For example, the PSBL could be paired with other 700 MHz spectrum other than the D Block or even paired with 800 MHz spectrum. Or 700 MHz "coverage spectrum" might pair with higher frequency "capacity spectrum". Let us remember that the D Block proposal was originally conceived as a way to provide incentives for one commercial licensee to partner with public safety. But it is not the only possibility**.** Conversely, if the Commission were to support a proposal based around existing spectrum-rich commercial providers, it is not clear at all why they would need the D Block.

Making matters even more challenging, the above operational considerations must be appraised in the context of a wireless industry structure that is currently very much in flux. Current transactions pending before the FCC and other industry changes – including the pending Verizon-Alltel merger, the New Clearwire joint venture, the Sprint Nextel turnaround, and the recently announced restructuring of Motorola, the largest existing provider of public safety networks and equipment – will significantly affect who are the likely players offering viable solutions.

In conclusion, let us remember that decisions made by the FCC in this rulemaking process will shape the contours of the technical and operational approach employed by thousands of state and local agencies for years, possibly decades, to come. In order to reach the right decisions for our first responders and our country, the FCC must:

understand public safety's requirements
understand the technology issues
understand the economic issues
and understand the outcome of pending shifts in industry structure

and then create the right rulemaking.

The normal rulemaking process thus far has proved inadequate for providing the FCC the needed understanding. The FCC should consider creating a fact-finding council of reputable technologists and economists representing the myriad stakeholders, including the public safety community, the manufacturing community, and the network operator community. The FCC should then charge this council with providing objective input on these complex issues.

Only with such input can the right decisions be made that will lead to the building of the Nationwide Interoperable Broadband Network Capabilities our first responders and critical infrastructure providers need.

Appendix A

May 8, 2007

Via Electronic Filing

Marlene H. Dortch
Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554
Re: WT Docket No. 06-150 and PS Docket No. 06-229
Ex Parte

Dear Ms. Dortch:

Pursuant to Section 1.1206(b)(2) of the Commission's Rules, this is to notify you that on Thursday, May 8, 2008, I and Dr. Cheryl Newman met with Jeff Cohen of the Public Safety and Homeland Security Bureau and Paul Murray of the Wireless Telecommunications Bureau at their request to discuss technology and engineering economic issues vis-à-vis implementing a Nationwide, Broadband, Interoperable Public Safety Network in the 700 MHz Band

Sincerely,

Stagg Newman
41 Pisgah View Ranch Rd.
Candler, North Carolina, 28715
1-828-665-1531
stagg@pisgahvu.com
Former Chief Technologist
Federal Communications Commission

cc: Jeff Cohen
Paul Murray

Implementing a Nationwide, Broadband, Interoperable Public Safety Network in the 700 MHz Band.
Talking Points

KEY POLICY OBJECTIVES RAISED AT CONGRESSIONAL HEARING

I. Build the Future Network Capabilities Needed for the **Public Safety** Community and **Critical Infrastructure**/Services Industry

II. Create **More Competition** in the Cellular Market

Major New Entrant (challenging w/ only D Block/PS Spectrum)

Roaming Alternatives for 2nd, 3rd Tier and Rural Players

III. Create a **3rd Pipe** Alternative to DSL and Cable

-A TRUE PIPE DREAM - NOT FEASIBLE WITHOUT >100 MHz of Prime Spectrum Real Estate

BUILD THE FUTURE NETWORK CAPABILITIES FOR PS COMMUNITY AND CII Providers

I. Provide **Broadband Wireless Access**

II. Provide **Services** for the Public Safety

Data services

- Internet access to edge based IP applications
- New peer-to-peer applications

Voice Services

- Cellular services for first responders
- Mission Critical Voice Service (e.g. P25 defined services)

Video Services

(*Today these are **very different** services)*

III. Provide **Interoperability** among public safety systems and services

This is primarily a logical network problem, NOT an RF access problem. The Commission's R&O implied that this issue was to be solved but begged the question of how and by whom.

The Commission's plan needs to articulate how each of these capabilities will be met by whom and with what resources and funding sources.

From a spectrum standpoint there are three business models that can be used, particularly *vis-à-vis* Broadband Wireless Acccess for PS/CII..

THREE BUSINESS MODELS FOR BROADBAND ACCESS FOR PS/CII

I. **Dedicated 700 MHz Network** for Public Safety

Use all or part of 700 MHz Public Safety allocated spectrum for a dedicated shared broadband public safety network

Make best use of existing non-700 MHz narrowband spectrum to obviate need and expense of building new 700 MHz narrowband trunked radio systems.

Requires funding source for network build and on-going network operations

Find firm to build and operate network on behalf of public safety community

Develop model to handle governance, AAA, accounting, …

This is the model used in UK and other European Countries.

II. **Priority Services** for Public Safety on Commercial Cellular Networks

Features and functions needed by public safety (many are being driven by enterprise needs, some will be specialized)

Reliability, robustness, and availability needed (cellular networks in urban areas may be approaching or possibly surpassing PS narrowband trunked performance)

Coverage (cellular networks fall far short of PS coverage)

- Supplement cellular network build-out in existing spectrum?
- Build “thin overlay” network in 700 MHz spectrum?
- Use satellite network as universal “backstop network”?

This is the model used in wireline network today. We do NOT build separate physical wireline networks for public safety, government agencies, etc. Some of these networks are very very reliable (e.g. Federal Reserve Network). So key question is: can wireless coverage and reliability under this model meet public safety needs?
This model may well be most cost effective model in the same way as in wireline world if the proper incentives and/or mandates can be found.

III. Public Safety/D Block 700 MHz **Partnership Model**

Monopoly Wholesale Provider of Access, Monopoly MVNO provider of services

Wholesale Provider of Access, Many System Integrators provide services

Integrated Provider of Services

The Monopoly Wholesale Provider of Access, Monopoly MVNO provider of services was the model used in the 2007 R&O and PSST Bid document.
For any of the models a critical question for economic viability is what capacity must be allocated under what circumstances to whom as that determines how much capacity the D Block licensee has to offer for commercial services to make business model work.

Broadband wireless data access?

Cellular service for public safety in lieu of purchasing services from today's cellular providers?

Only public safety users of agencies entitled to 700 MHz spectrum by statute or all public safety and government workers (local, state, and federal) and CII users?

PUBLIC SAFETY/D BLOCK PARTNERSHIP MODEL

Key factors to analyze for a successful National Public Safety 700 MHz Network D Block/Partnership

I. **Services Model.** Proper definition of the services required and timing and the services *not* required

Broadband Wireless Internet Access

- Wholesale Transport?
- Enablers for Retail Applications?

Voice

- Cellular Voice?
- Mission Critical Public Safety Voice Services w/ Command and Control?

Interoperability

- For Internet transport
- For Applications
- For voice
  - In 700 Mhz broadband spectrum?
  - Acrosss legacy systems and the 700 MHz BB spectrum (this is a BIG issue and NOT primarily a 700 MHz spectrum issue but the past rulemaking lacked clarity and was ambiguous on this crucial point)
  - Handset portability

II. **Business/Operational Model.** Business alignment between Public Safety at local/state level, PSST, and D Block licensee

Role of transport provider

- Single nationwide network?
- Regional operators under centralized direction for compatibility and interoperability?
- Wholesale provider and/or wholesale and retail service provider?

Role of local agencies in choosing retail service providers

- One MVNO provided by PSST and its agent is only purchaser of wholesale transport?
- Many service providers and systems integrators that can purchase transport on behalf of local/state agencies as well as single nationwide "*uber* network", i.e. the "Network of Networks model"?
- Agent of PSST as technical advisor, business advisor and/or retail MVNO (orders of magnitude difference in financial size of agent under these models)?

Eligible users/service for wholesale transport at most favorable rates

- Emergency services or all services for eligible users?
- Public safety agencies authorized by statute or all members of the "safety community" and other government agencies?.

III. **Cost Drivers**

Coverage requirements

- Geographic coverage
- Population coverage
- Jurisdictional Coverage
- Role of satellite in meeting ubiquity requirements (w/ acceptable quality
  - For data?
  - For cellular quality voice?
  - For mission critical voice?
- In-building requirements
- Vehicular mobility requirements
- Subscriber devices
  - Vehicular
  - Public safety "grade and power"
  - Consumer type low power handhelds

Availability of civil infrastructure and existing networks

- Role of public safety owned or leased sites, particularly high site towers
- Role of existing cellular networks
- Role of utility networks

Backhaul

Robust, reliability, performance

- Services requirement and/or
- Network component requirements?

Subscriber equipment – *the most important life cycle cost driver*

- Commonality of equipment to achieve volume
- Use of COTS equipment or components and chip sets
- Role of multi-mode multi-band technology multi-function technology
    - Satellite?
    - Broadband data?
    - VoIP?
    - P25 functionality?

Appendix B

White Paper

750 MHz RF Coverage Design for the State of North Carolina

A Network Design by Actium Advisors
Developed for Frontline Wireless
in Cooperation with the North Carolina State Highway Patrol

August 3, 2007

Contents

1 Executive Summary

This White Paper describes the a proposed 750 MHz radio frequency coverage design for the state of North Carolina. The design incorporates the distinct requirements of Public Safety agencies and critical infrastructure providers, as well as commercial customers, into a single network. The final result is a network that provides the following services levels:

Public Safety and Critical Infrastructure	Commercial
95% area coverage of the entire state of North Carolina	90% area coverage of 85% of the population of North Carolina
1.0-1.2 Mbps forward link average data rate (300 kbps at cell edge)	1.0-1.2 Mbps forward link average data rate (300 kbps at cell edge)
450-750 kbps reverse link average data rate (75 kbps at cell edge)	450-750 kbps reverse link average data rate (50 kbps at cell edge)
1.5 Watt vehicle roof-mounted radio	250 milliwatt handheld mobile device

The network as designed consists of 283 sites, most of which utilize existing sites that could be made available by the North Carolina State Highway Patrol or other state and local government organizations.

Frontline's proposed Public Safety and commercial coverage footprints provide significantly better coverage than that claimed by incumbent cellular operators today. In practical terms, Frontline's design represents a major leap forward for Public Safety agencies in the North Carolina: service will be available in at least as many areas as it is today, and at data rates 30X greater than that provided by the existing North Carolina Criminal Justice Information System (CJIN) Mobile Data Network (MDN)[1]. Moreover, Frontline's design assures broadband coverage on virtually all roads, regardless of how rural or mountainous the terrain, and in many cases provides coverage off-road in these same remote areas. Even vehicles exceeding 100 miles per hour will be able to achieve the committed broadband data rates.

We selected the state of North Carolina, in part, because its geographic diversity – encompassing coastal, piedmont, and mountainous regions – provides an

[1] The CJIN MDN is a statewide Public Safety mobile data network managed by the NC State Highway Patrol. It utilizes approximately 170 tower sites operating in the 800MHz Public Safety band, and currently serves more than 12,000 officers and 350 law enforcement agencies. The CJIN MDN is based on Motorola iDen/RDLAP technology, and though transmitting 19.2 kbps over the air, the actual usable data rate is closer to10 kbps - shared by all officers in the coverage area of a given base station.

excellent representation of common geographies found across the United States. In the future we may explore the possibility of using this network design to estimate the number of base stations required to provide a similar level of service to the entire country.

2 Network Design Methodology

Frontline's 750 MHz radio frequency (RF) design for the state of North Caroline follows the conventional methodology for designing digital wireless networks. First, we define the *end user services* and *network coverage objectives*. End user services are expressed in terms communication data rates on the forward and reverse communication links; whether the end user is mobile or stationary; and whether those services are available inside buildings or cars in different morphologies. Morphology refers to the density and type of build structures in a geographic area. In this network design, we recognize the following different types of morphology types:

Morphology	Population / Square Mile
Dense Urban	15,000+
Urban	5,000-15,000
Suburban	750-5,000
Rural	250-750
Open area	0-250

Network coverage is expressed as the probability of the network being able to provide the defined services throughout the coverage area of a base station. Frontline is committed to providing 95% area coverage to Public Safety agencies throughout the entire geographic area of North Carolina, and 90% area coverage to commercial customers across 85% of the population of North Carolina. The network design ensures that both Public Safety agencies and commercial customers will typically achieve data rates of 1.0 – 1.2 Mbps on the forward link and 450 – 750 kbps on the reverse link.

Next, we construct link budgets for both Public Safety agencies and commercial customers that mathematically model the various elements along signal path that amplify or attenuate the signal. We then select an RF propagation model that adequately predicts signal coverage in the area we wish to serve. Finally, we predict the actual network coverage based on the use of existing or new communication towers.

Throughout the process, we rely on industry standard practices and extensive experience in real world deployments.

3 Frontline Service Description

Frontline intends to deploy a nationwide broadband wireless network that serves the needs of Public Safety agencies on a priority basis while also providing commercial broadband wireless services on a secondary basis. In conjunction with its partners, Frontline will provide Public Safety agencies and critical infrastructure providers a nationwide, interoperable broadband transport network. Likewise, Frontline will provide commercial customers with a nationwide, open access, wholesale network that will enable many different retail services to meet local, regional, and industry specific communication needs.

By serving the needs of both Public Safety agencies and commercial users on a single network, Frontline is able to offer its Public Safety and critical infrastructure partners a route to nationwide broadband wireless service that is faster and less expensive than other alternatives, while still providing these organizations with the state-of-the-art in broadband wireless technology.

3.1 Public Safety and Critical Infrastructure

3.1.1 Communication services

Public Safety agencies include fire fighters, law enforcement and emergency medical services (EMS) personnel at the federal, state and local levels. Public Safety agencies have a wide array of broadband wireless communications needs, including streaming video, still images, Voice over Internet Protocol (VOIP), alerts, data files, and database queries. Streaming live video is the most bandwidth intensive service, and may include applications such as police helicopters transmitting video of conflagrations to fire commanders; fire apparatus and fire helmet video camera feeds from fire scenes; and traffic cameras indicating optimal routing for first responders.

The following table describes the range of Public Safety services that Frontline intends to support in its network design. The priorities indicated have been selected based on urgency of need by Public Safety, and concomitantly, the lack of alternative services today.

Priority	Service	Description
1	Video upload	Video from Public Safety officials in the field, transmitted over the reverse link (mobile to base station) to a command center or central processing facility 75 kbps is a sufficient data rate to prevent video from becoming grainy and jumpy, provided that Public Safety vehicles on the scene have built-in repeaters to boost the signal-to-noise ratio; otherwise 200 kbps is needed
2	Video download	Video sent to a mobile command center,

		transmitted over the forward link (base station to mobile) 200 kbps is sufficient to provide necessary video quality
3	Photo (image) download	Mug shots and other still images transmitted to a crime scene over the forward link Very low data rates (below 50 kbps) do not affect image quality but do affect download times
4	Voice services	Voice communication services using voice over IP (VOIP) sent in full duplex mode (both parties may speak at the same time) over the forward and reverse links 50 kbps data rate is required for adequate voice quality
5	Remote data access	Queries to remote databases; software applications utilizing HTTP-based Web services; other proprietary data communications; all utilizing the forward and reverse links Very low data rates (below 50 kbps) do not affect data quality but do affect download times

3.1.2 Usage Scenarios

Public Safety agencies must perform their duties wherever disaster strikes – from dense cities to uninhabited mountainous areas. Public Safety officials are assumed to be mobile, either in automobiles or other emergency response vehicles, and these vehicles may be moving at high speed. Public Safety officials utilize handheld and roof-mounted radios with far greater transmit power than commercial cellular telephone. Accordingly, the principal usage scenario for Public Safety agencies involves an official traveling in a vehicle at a high rare of speed and utilizing a high power radio and roof-mounted antenna. In this scenario, the official requires sufficient wireless data throughout to perform a vehicle license plate query or to place and receive VOIP communications.

The Frontline network design assures that Public Safety agencies and critical infrastructure providers will be able to achieve cell edge data rates of 300 kbps forward link and 75 kbps reverse link over 95% area coverage in a moving vehicle anywhere in North Carolina. Typical data rates (not at the cell edge) will range 1.0 - 1.2 Mbps forward link and 450 – 750 kbps reverse link. The network design will provide the committed cell edge data rates to vehicles moving in excess of 100 miles per hour. The network design does not guarantee that Public

Safety officials will have broadband coverage inside buildings throughout the entire state of North Carolina, though such coverage will be available throughout the vast majority of the coverage footprint.

3.2 Commercial

3.2.1 Communication services

Commercial customers comprise the full range of Internet users, with applications ranging across business, education and entertainment. Through its wholesale, open access business model, Frontline intends to support the full array of broadband wireless services one expects from a "wired" PC in the home: email, Web browsing, social networking, VOIP, and music and video downloads.

3.2.2 Usage scenarios

The Frontline network design assures that commercial customers will be able to achieve cell edge data rates of 300 kbps forward link and 50 kbps reverse link over 90% area coverage in the following usage scenarios:

In a moving vehicle, in any morphology within the coverage area.

While walking in a residence constructed of wood, including interior rooms, in any morphology

While walking in a building constructed of concrete and steel, on any floor of the building, in urban and dense urban morphologies.

As with Public Safety officials, commercial customers will often achieve data rates much higher than the committed minimums, even in situations that are beyond the network design objectives. Typical data rates (not at the cell edge) will be 1.0 - 1.2 Mbps forward link and 450 – 750 kbps reverse link, exceeding the wireless broadband data rates provided today by the leading cellular operators.

3.3 Summary of Frontline services

The following table summarizes the cell edge service levels[2] utilized by Frontline in producing its network design:

	90% area coverage	95% area coverage
	1.0-1.2 Mbps FL, 450-750 kbps RL (avg)	1.0-1.2 Mbps FL, 450-750 kbps RL (avg)

[2] Frontline's expected average and cell edge data rates are predicated on the use of standard 1.25 MHz communication channels. Emerging technologies such as LTE and WiMAX, with 5 MHz and greater channel bandwidths, promise to increase data rates by at least a factor of 2. Burst data rates, observed in the optimal radio environments, may exceed 14 Mbps forward link and 5 Mbps reverse link.

	300 kbps FL, 50 kbps RL (cell edge) Covering 85% of the population of NC		300 kbps FL, 75 kbps RL (cell edge) Covering the land mass of NC	
	In-car moving	In-building walking	In-car moving	In-building walking
Public Safety & CI All morphologies	✓	✓	✓	
Commercial All morphologies	✓	✓		

The data rates indicated are based on the RF coverage design presented in this White Paper. The actual final design will incorporate frequency re-use to minimize interference between adjacent towers, thereby increasing the cell edge data rates beyond the levels shown here.

4 Network Design

4.1 Coverage objectives

Frontline must balance the need for basic coverage over a large geographic area with the need to support high capacity usage in any single area. As in all wireless network designs, Frontline seeks first to provide basic coverage across its licensed service area, and then later to provide additional capacity throughout its service area, based on observed usage and demand for services. This White Paper addresses an RF design that provides basic coverage.

Taking into account the end users services and usage scenarios discussed in Section 3, Frontline seeks to provide 95% area coverage to Public Safety agencies throughout the geographic area of North Carolina, and 90% area coverage to commercial customers over 85% of the population of North Carolina.

“Area coverage” is defined as the probability of providing the committed forward link and reverse link data rates within the geographic area covered by a base station transmitter. Area coverage takes into account the “fast” signal fading associated with serving mobile users, as well as the “slow” fading associated with normal signal propagation over different morphologies.

An area coverage probability over the entire area served by a base station transmitter can also be expressed as a cell edge coverage probability. Frontline’s 95% area coverage objective for Public Safety agencies equates to a cell edge coverage probability of about 83%[3]. Likewise, the 90% area coverage objective for commercial customers equates to a cell edge coverage probability of about

[3] Insert ref

73%[4]. In other words, a Public Safety agencies operating at the cell edge will have an 83% probability of achieving forward link and reverse link data rates of 300 kbps and 75 kbps, respectively.

4.2 Link budget

A link budget quantifies the gains and losses in the signal transmission path between a base station and a mobile device. Link budgets are defined for the forward link from the base station to the mobile device, and the reverse link from the mobile device to the base station. Both the forward link and the reverse link have a net path loss, representing the maximum signal loss that can be tolerated before the communication link is lost. Generally, the forward link has a higher path loss figure than the reverse link, since base stations generally transmit at higher effective power than mobile devices and can therefore tolerate greater attenuation. Radio engineers describe link budgets as being "balanced," meaning that the path loss is same in the forward and reverse links. Since most link budgets are not naturally balanced (due to differences in transmit power between the base station and the mobile device), the path loss of the more robust link is often reduced to equal that of the weaker link, and the difference is expressed as "margin."

In this White Paper, we define separate link budgets for Public Safety agencies and commercial customers, and we then use the worst case path loss figures from both link budgets to define the overall system path loss. This assures that final network will always meet its most demanding performance requirements. The link budgets, presented below, include typical values for elements such as cable and connector loss, body loss, and antenna gains. The key drivers in the link budgets are as follows:

Vehicle-mounted Public Safety radio transmit power – Mobile data radios used by the North Carolina State Highway Patrol transmit at 15 – 20 watts EIRP through roof mounted antennas that provide 2 dB of net gain. The resulting transmit power is 45 dBm EIRP, or more than 30 Watts EIRP. This is a very high power level relative to handheld radios or cellular phones, which typically transmit at about 24 dBm (or 250 milliwatts) EIRP. For the purposes of this White Paper, we have assumed that a 1.5 Watt EIRP (32 dBm EIRP) mobile radio will be used for Public Safety in-vehicle communications. As a result of using high power, vehicle mounted radios, the link budget for Public Safety is limited by the forward link, not the reverse link, as is normally the case. This means that the commercial forward link path loss (as opposed to the Public Safety reverse link path loss) drives the overall system design.

Cell edge data rate – Frontline seeks to provide a minimum forward link data rate of 300 kbps to both Public Safety agencies and commercial customers, and minimum reverse link data rates 75 kbps and 50 kbps, respectively, to Public Safety agencies and commercial customers. These data rates dictate the

[4] Insert ref

sensitivity required by a modern receiver operating in a 1.25 MHz channel to detect and process the signal above the thermal noise floor.

Fade margin – Fade margin accounts environmental contributions to path loss. The "fast fade margin," or Rayleigh fade margin, accounts for signal losses associated with the end user either moving or remaining still. Typically, a fast fade margin of 1.5 dB is used when designing to serve end users who are not moving, and 6.0 dB to serve end users who are moving at vehicular speeds. The "log normal fade margin" accounts for signal losses attributable to the area coverage probability associated with the system's mobility and morphology requirements. The log normal fade margins for the Public Safety link budgets are higher than those for the commercial link budget due to the higher area coverage requirement for Public Safety (95% vs 90%). Fast fade margin and log normal fade margin are additive, thereby creating between 9 dB and 11.5 dB of fade margin in the various link budget scenarios.

Car, home and building losses; and morphology – The link budgets model the usage scenarios defined in Section 3. Specifically, the link budgets assume that signals will experience losses of 8 dB, 12 dB, and 20 dB, respectively, when passing through cars, homes constructed of wood, and office buildings constructed of concrete and steel. These losses are linked to specific morphologies: building losses of 20 dB (office buildings) are only budgeted for urban and dense urban areas; building losses of 12 dB (homes) and car losses of 8 dB are budgets for all morphologies.

4.2.1 Forward link budget

		Commercial				Public Safety
		In Car	in Home	In Building		Car w/ mag mount
Mobility		Full	Nomadic	Nomadic		Full
Forward Link	**Unit**	**Values**	**Values**	**Values**		**Values**
BTS RF PA output	dBm	41	41	41		41
BTS cable loss	dB	3.0	3.0	3.0		3.0
BTS connector loss	dB	0.5	0.5	0.5		0.5
Total RF PA output	dBm	**37.8**	**37.8**	**37.8**		**37.8**
Percent Pilot power	%	15.0%	15.0%	15.0%		15.0%
Percent Trafficl power	%	65.0%	65.0%	65.0%		65.0%
Overhead channel power %	%	20.0%	20.0%	20.0%		20.0%
BTS antenna gain (dBi)	dBi	12.2	12.2	12.2		12.2
Total EIRP	dBm	**50.0**	**50.0**	**50.0**		**50.0**
Pilot EIRP	dBm	41.8	41.8	41.8		41.8
PC Card / mobile antenna gain (dBi)	dBi	48.1	48.1	48.1		48.1
Thermal noise per Symbol/tone	dBm/tone	-133.49	-133.49	-133.49		-133.49
Mobile NF	dB	9	9	9		9
Total data rate (kbps)	kbps	900	900	900		300
SiNR Required for rate	dB	7	7	7		-1
RX sensitivity for rate	dBm	-117.69	-117.69	-117.69		-125.29
MS Rx pilot power	dBm	-107.2	-107.2	-107.2		-114.8
Interference margin	dB	2.5	2.5	2.5		2.5
Rayleigh fade margin	dB	6.0	6.0	6.0		6.0
Log-Normal fade margin	dB	3.0	3.0	3.0		5.5
Car/Home/Building penetration loss	dB	8	12	20		0
Path Loss	**dB**	**127.5**	**123.5**	**115.5**		**144.6**
Pilot Power Coverage Threshold	dBm	**-85.7**	**-81.7**	**-73.7**		**-102.8**

4.2.2 Reverse link budget

		Commercial				Public Safety
		In Car	in Home	In Building		Car w/ mag mount
Mobility		Full	Nomadic	Nomadic		Full
Reverse Link (Uplink)	**Unit**	**Values**	**Values**	**Values**		**Values**
MS PA output	dBm	21.0	21.0	21.0		30.0
Mobile antenna gain (dBi)	dBi	-2.0	-2.0	-2.0		2.0
Total EIRP	dBm	**19.0**	**19.0**	**19.0**		**32.0**
BTS RX antenna gain (dBi)	dBi	12.6	12.6	12.6		12.6
BTS cable loss	dB	3.0	3.0	3.0		3.0
BTS connector loss	dB	0.5	0.5	0.5		0.5
Thermal noise per Symbol/tone	dBm/tone	-133.49	-133.49	-133.49		-133.49
BTS noise figure	dB	4	4	4		4
Diversity gain (2x2 MIMO UL Only)	dB	2.5	2.5	2.5		2.5
Total data rate (kbps)	kbps	66	66	66		75
SINR Required for rate	dB	1	1	1		3
Receiver sensitivity	dBm	-116.56	-116.56	-116.56		-114.88
Interference margin	dB	2.5	2.5	2.5		2.5
Rayleigh fade margin	dB	6.0	6.0	6.0		6.0
Log-Normal fade margin	dB	3.0	3.0	3.0		5.5
Car/Home/Building penetration loss	dB	8	12	20		0
Max path loss	dB	**129.8**	**123.6**	**115.6**		**144.5**
Pilot Power Coverage Threshold	dBm	**-88.3**	**-82.2**	**-74.2**		**-102.7**

4.3 System Path Loss and Pilot Power Threshold

The following table summarizes the aggregate path loss along the forward and reverse links for both commercial and Public Safety networks. The path loss figures highlighted in red represent the communication links that can tolerate the least path loss; these links define the limits of system coverage. All other links can tolerate greater path loss, and therefore have additional margin to complete the communication path.

	Forward Link Path Loss (dB)		Reverse Link Path Loss (dB)	
Morphology	**Commercial**	**Public Safety**	**Commercial**	**Public Safety**
Open Area	127.5	144.6	129.8	144.5
Rural	127.5	144.6	129.8	144.5
Suburban	123.5	144.6	123.6	144.5
Urban	115.5	144.6	115.6	144.5
Dense Urban	115.5	144.6	115.6	144.5

For each of the worst case links above, we determine the corresponding pilot power threshold. In 4G wireless systems such as 802.16e WiMAX, EV-DO and Flash OFDM, the pilot signal enables mobile device to coherently detect and attach to the wireless network. The pilot channel typically consumes 15% of the total output power of the base station. By subtracting the path loss from the pilot power at its point of transmission, it is possible to determine the pilot power threshold. The pilot must be at or above its threshold in order for communications to occur. The pilot power threshold therefore defines the geographic boundary of coverage of a base station.

Morphology	Worst Case Path Loss (dB)	Worst Case Pilot Power Threshold (dB)
Open Area	127.5	-85.7
Rural	127.5	-85.7
Suburban	123.5	-81.7
Urban	115.5	-81.7
Dense Urban	115.5	-73.7

4.3.1 Propagation model

The network design utilizes an RF propagation model that uses mathematical algorithms to predict the propagation of radio signals from specified base station transmitters. The most basic propagation algorithm is Free Space Path Loss, which predicts the propagation of a radio signal of a given frequency in a vacuum with no obstructions or echoes. More sophisticated propagation models take into account real world factors such terrain and foliage, building morphology, and the presence of waterways, which may allow signals to propagate further. The most sophisticated models may also be “tuned” or optimized to with signal strength data collected during actual drive tests of the market. Drive test data allows individual parameters of the propagation model to be adjusted to account for observed signal coverage.

This White Paper makes use of a widely accepted propagation model known as the Lee Model[5], which was developed by William C. Y. Lee. The Lee Model is particularly useful when performing a theoretical network design, before actual drive test data is available. The Lee Model incorporates the presence of waterways and clutter data to model signal dispersion due to the presence of buildings and other morphological characteristics. In this White Paper, we use the Lee Model with some waterway data but no clutter data.

An alternative propagation model that may be used in future analysis is the Okamura-Hata Model[6], which can be more accurate but tends to significantly under predict coverage when it has not been tuned with drive test data.

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[5] Lee, W.C.Y., "Mobile Cellular Telecommunications Systems", McGraw-Hill, 1989.

[6] Okamura, Y. a kol.: Field Strength and its Variability in VHF and UHF Land-Mobile Radio Service. Rev. Elec. Comm. Lab. No.9-10pp. 825 - 873, 1968. Hata, M.: Empirical Formula for Propagation Loss in Land Mobile Radio Services. IEEE Trans. Vehicular Technology, VT-29, pp. 317 - 325, 1980.

4.3.2 Site selection

The RF design in this White Paper assumed that every Frontline site utilized a 3-sector, dual polarization, 71º horizontal beamwidth antenna. We “placed” our antennas 3 meters below the lowest 800 MHz antenna on each tower; or if information about other tenant antennas was not available, we placed the Frontline antennas 6 meters from the top of the tower.

We attempted to use as many existing towers as possible, drawing from a database of towers used by the North Carolina State Highway Patrol and other state agencies (the “NC database”), as well as a database of commercially available towers from SBA Communications and Crown Castle.

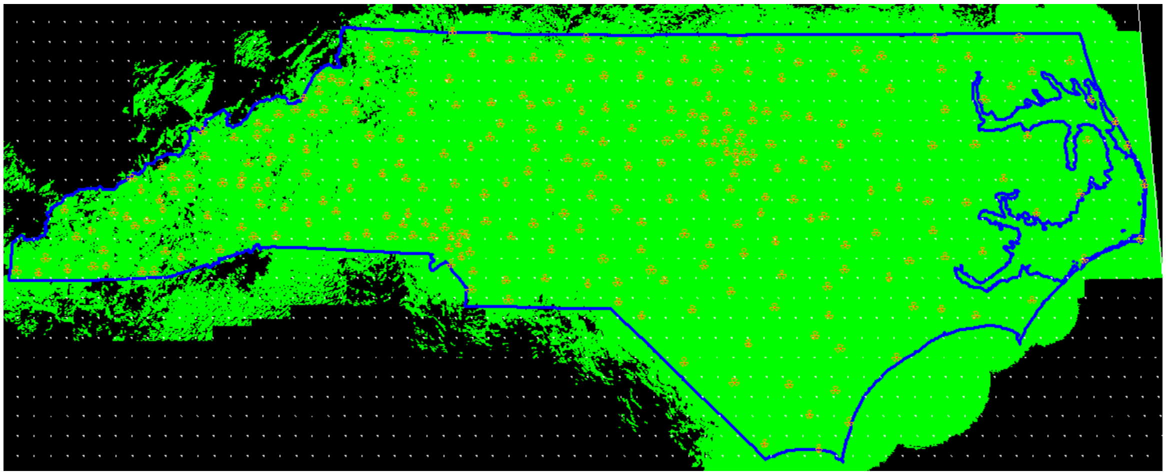
We used the following rules of thumb when selecting towers:

> If the NC database towers were taller than the commercial towers in a specific area, we selected the NC database towers; otherwise we used the commercial towers;
>
> If no existing towers were available, we assumed new (greenfield) towers at 200 feet height (generally towers at or below 200 feet do not require FAA lighting).

As expected, the tower databases contained some incomplete records and other inconsistencies typical of all large tower databases. We avoided using sites where database information was questionable unless no other options were available. In actual field deployment, of course, we will survey these sites, perform engineering studies for each site, and undoubtedly introduce changes to the network design to accommodate the reality on the ground.

4.4 Coverage maps

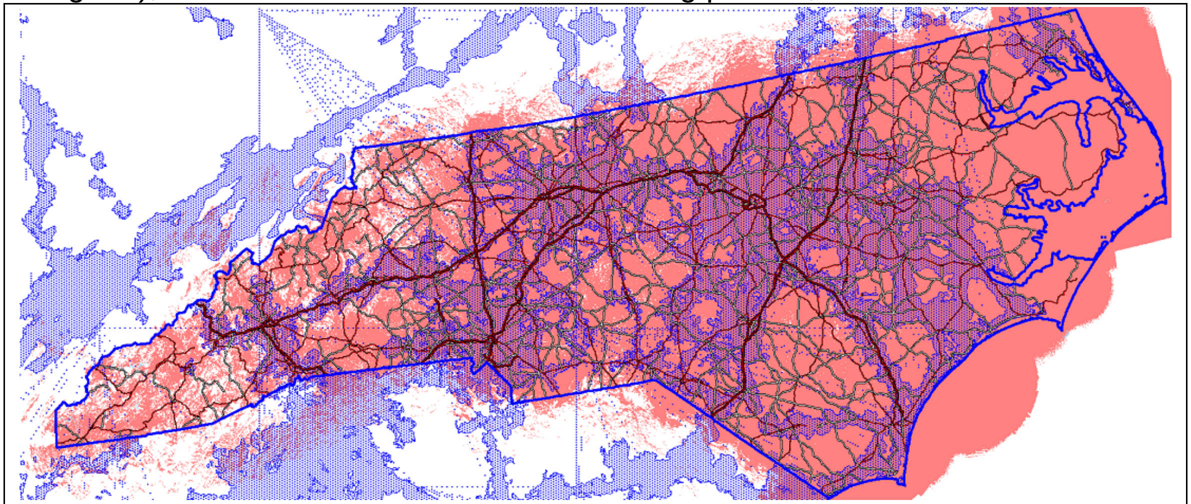
A map illustrating Frontline’s coverage of the state of North Carolina appears below. Each dot on the map represents a 3-sector base station. The area shaded in green indicates the area where a Public Safety device operating in a moving vehicle would be able to establish a communication link with a base station (experiencing path loss of 144.5 dB or less).



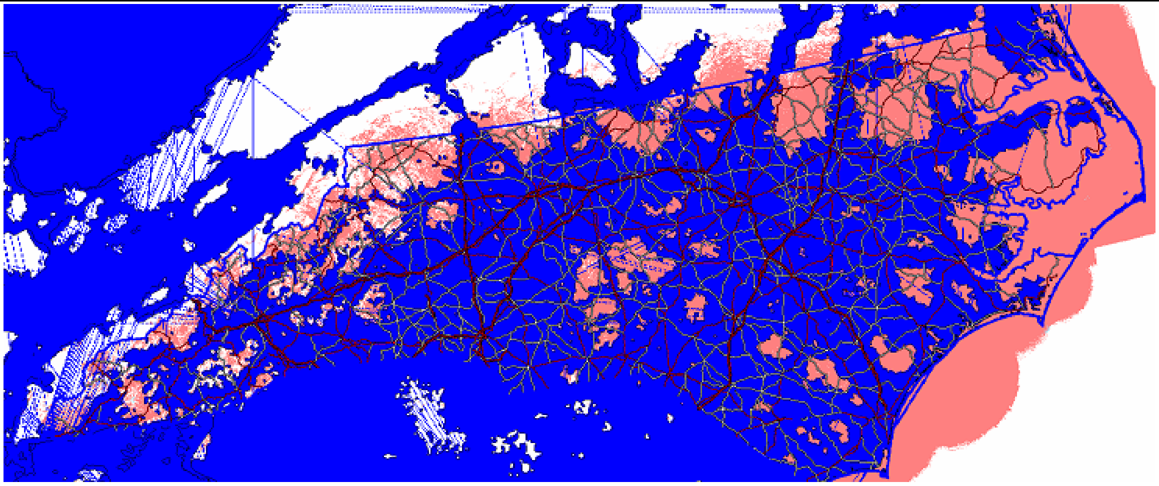
This network design includes the use of 283 3-sector base stations across the five morphology types, as indicated below:

Morphology	Cell Count
Open Area	7
Rural	262
Suburban	10
Urban	3
Dense Urban	1
Total	***283***

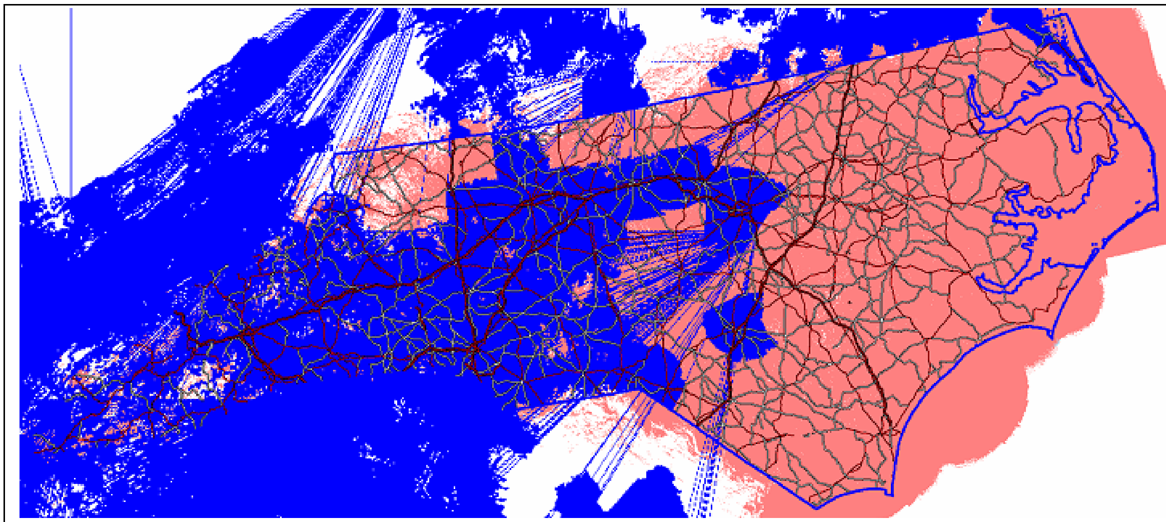
Frontline's Public Safety coverage equals, and many cases exceeds, the coverage provided by tier 1 commercial wireless operators today. The maps below provide an overlay of the Frontline coverage prediction for Public Safety agenices with the current coverage claimed by Sprint-Nextel, AT&T (formerly Cingular), and Verizon Wireless and its roaming partner, Alltel.



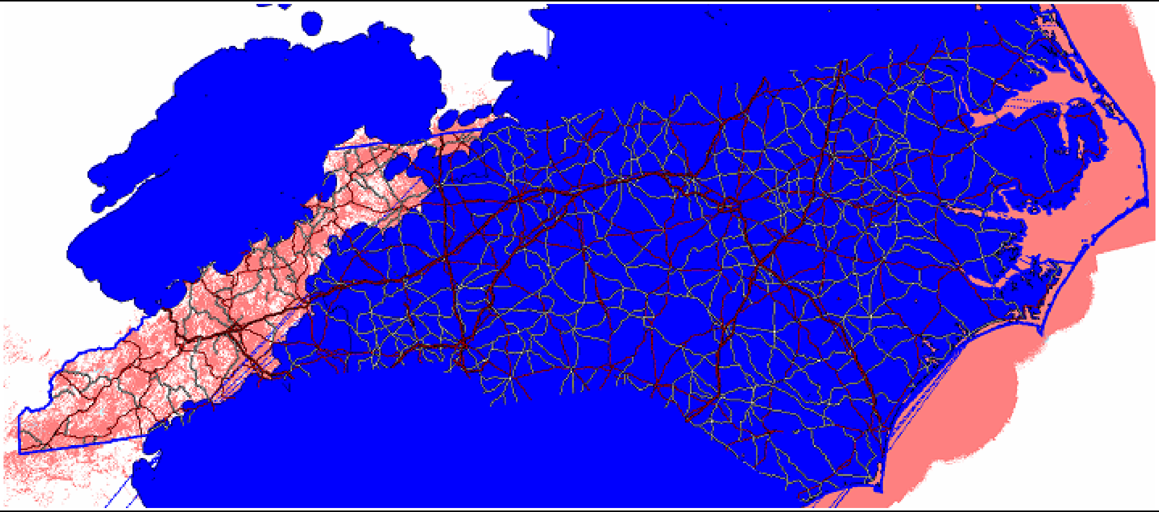
Frontline Public Safety (red) vs. Sprint-Nextel CDMA+iDEN (blue)



Frontline Public Safety (red) vs. AT&T (blue)



Frontline Public Safety (red) vs. Verizon Wireless (blue)



Frontline Public Safety (red) vs. Verizon Wireless roaming partner Alltel (blue)

5 About the Authors

Stagg Newman was CTO of Frontline Wireless and former Chief Technologist of the FCC. He is the Principle of Pisgah Comm Consulting.
Rodney Spell is APCO Frequency Coordinator for North Carolina and Manager of the North Carolina Criminal Justice Information Network (CJIN) Mobile Data Network (MDN)
Paul Allan Sadowski is the North Carolina State Highway Patrol IT Manager/Network Manager.
Mark McDowell is the Managing Partner of Actium Advisors.