Tutorial on TDD Systems

FCC Office of Engineering and Technology
Monday, December 3, 2001

Part 1: Overview of Duplex Schemes

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The TDD Coalition

It is the position of the TDD Coalition that with proper planning and regulatory considerations, TDD and other duplexing technologies can coexist in the same geographic and spectral space

Aperto Networks

Arraycomm

BeamReach Networks

Caly Networks

Clearwire Technologies

Harris Corporation

InterDigital

IP Wireless

LinkAir

Malibu Networks

Navini Networks

Pointred Technologies

Radiant Networks

Raze Technologies

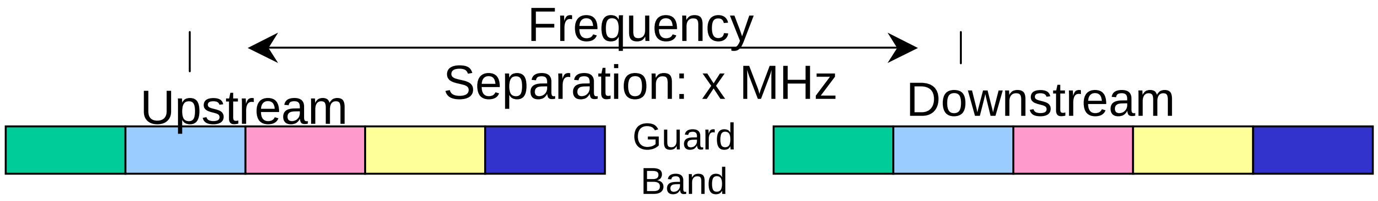
Wavion Ltd

Overview of the Duplex Schemes

- **Definitions**
  - FDD
  - TDD
  - Adaptive TDD
- **Comparison of TDD vs FDD**
  - Spectrum Efficiency
  - Spectrum Allocation and Utilization
  - Deployment and Network Planning Issues
  - Compatibility with emerging applications and all-IP networks with asymmetric traffic
  - Adaptability to advanced signal processing (adaptive antennas, user terminal beam-forming, etc.)
  - Field trials

FDD – Frequency Division Duplexing

- **Separate in frequency the downstream and upstream directions of the traffic**
- **Ratio between downstream and upstream traffic fixed by equipment design**
  - 1/2 - 1/2 for voice
  - 2/3 – 1/3 for data (typical for 16QAM down, 4QAM up)
- **FDD requires a guard band between the downstream and upstream**



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TDD – Time Division Duplexing

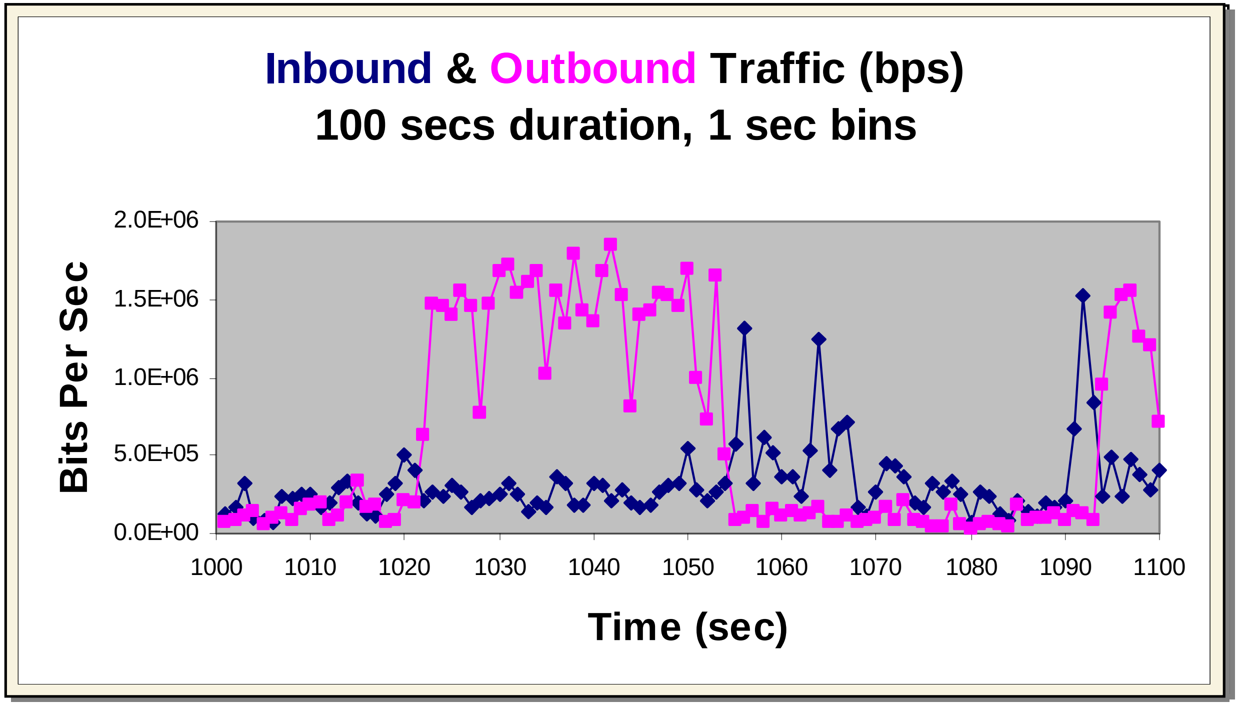
- **Separate in time the downstream and upstream directions of the traffic**
  - An example of TDD is half-duplex transmission on an HF communication system using a push-to-talk switch
- **Use a single frequency for both downstream and upstream**
- **Ratio between downstream and upstream traffic can be fixed or adaptive**
- **TDD requires a guard time between the downstream and upstream but no guard band**

Data Traffic Asymmetry

LBL traffic is nearly *symmetric* *averaged over 2 hours (53/47)*

but

asymmetric
over
shorter intervals

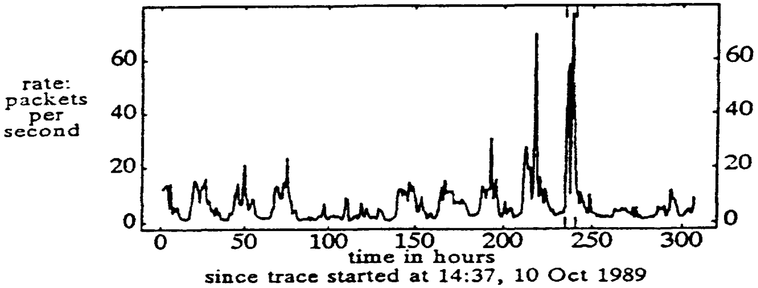


Statistics Averaged Over 2 Hour Trace:
Aggregate: 392 kbps
Inbound: 185 kbps
Outbound: 207 kbps

Real-Time Adaptive TDD

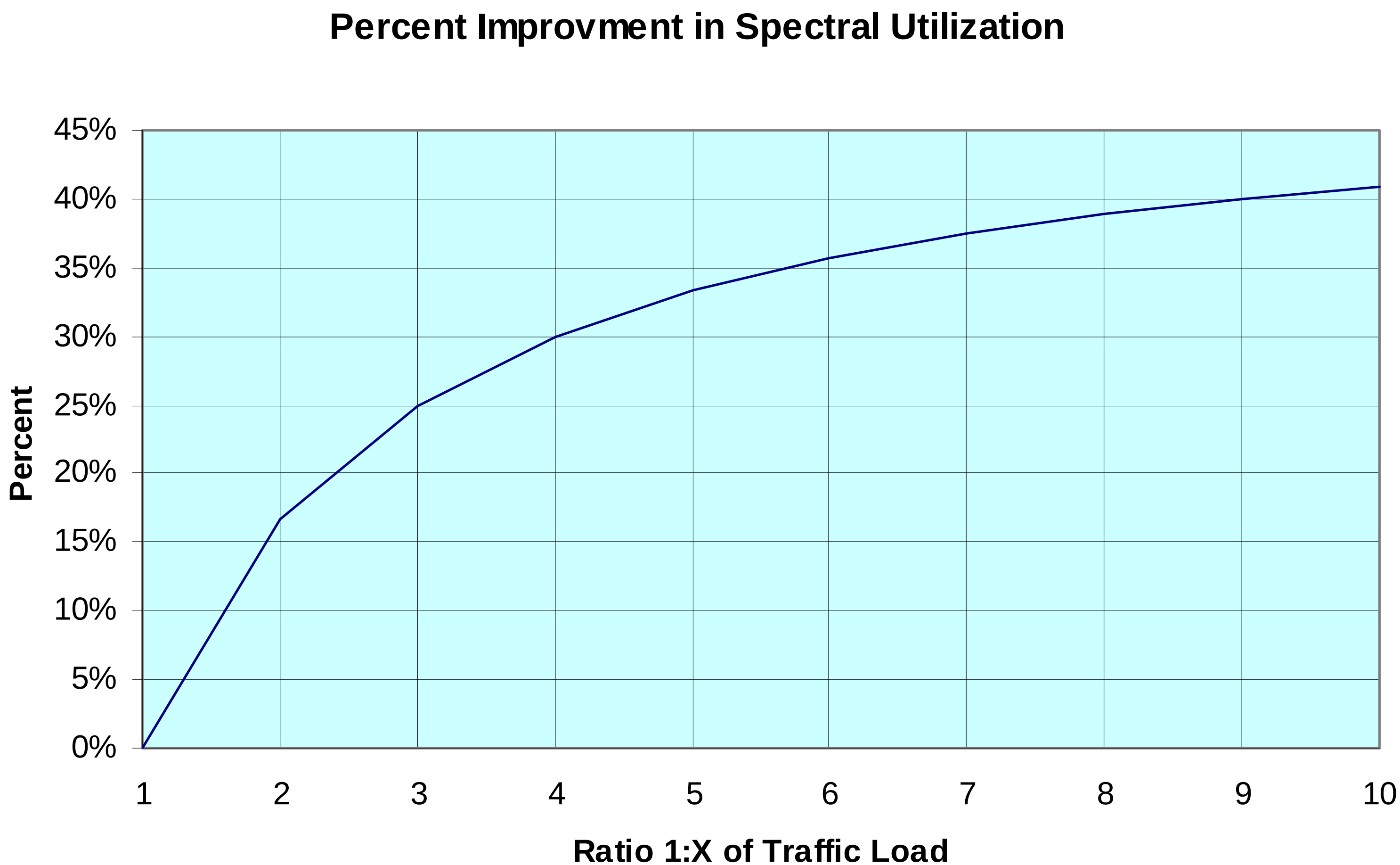
- **Real-time adaptation provides highest transport efficiency**
  - Millisecond real-time adaptation
  - 35% improvement over FDD/TDMA

Figure 3.2.1a: Hourly arrival rates of external traffic



- **TDD enables 100% use of available spectrum**
  - Well-suited for wide, single block allocations <u>and</u> narrow, dual block allocations
- **Minimal latency variation enables prioritization of preferred subscribers and critical applications**

Spectral Efficiency



With asymmetric traffic (data), TDD systems use spectrum more efficiently than FDD systems.

Spectral Efficiency

- **Minimize guard band**
- **Change symmetry on the fly depending on subscriber's needs**
- **Adaptive downstream/upstream ratio allows for emerging new applications without the need for spectrum re-farming**
- **Enables advanced technologies such as mesh network and adaptive antenna arrays**
- **Highly effective for bursty data traffic while still supporting voice**

Spectrum Allocation and Utilization

- **TDD allowed by the FCC, CEPT, Japan, Canada and many other countries**
- **Some countries still need to be convinced**
- **FDD absolutely requires paired spectrum**
- **TDD can be used with paired and unpaired spectrum**

  "TDD can use either sub-band and the middle guard band"
  (from an ITU-R Recommendation)
- **Block edge mask contributes to TDD/FDD coexistence**
- **New mitigation techniques are being developed**

  (Autonomous Frequency Allocation – AFA for example)

A Proven Technique

- Used successfully since many years with DECT and PHS
- Successfully deployed in recent UTRA-TDD multi-site field trial
- Supported by the recently released IEEE 802.16 standard and by the developing IEEE 802.16a
- Multiple studies demonstrated coexistence feasibility (IEEE 802.16.2 and CEPT reports)

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Part 2: Worldwide TDD Deployments

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Outline

- **TDD - Worldwide**
- **TDD - Motivation**
- **Mobile Wireless**
  - Cordless
  - 3G
- **Fixed Wireless**
  - WMAN
  - WLAN / WPAN
- **Emerging Technologies**

TDD is widely used

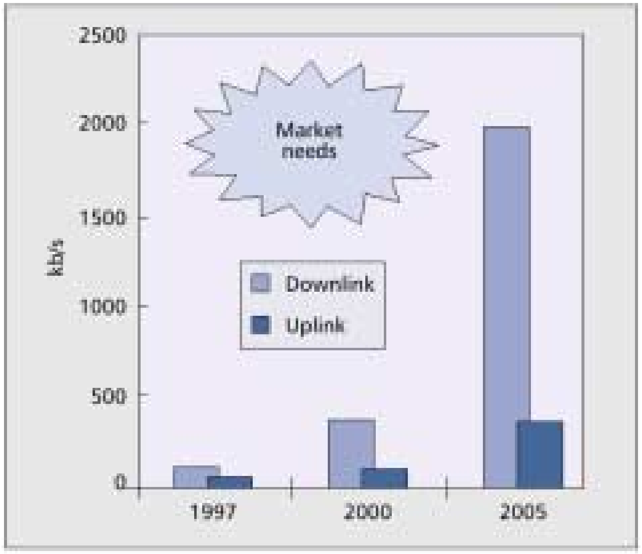
- TDD is used in ETSI standards, IEEE standards, MMAC, and in many proprietary systems
- There are many compelling reasons for this choice

Internet
Efficiency
Mesh
Packet services
Downlink Processing
Space-time processing
Cost
DSP
Unpaired Spectrum
Adaptive TDD
Asymmetry
Power control
Array processing
Simpler
Reciprocal Channel

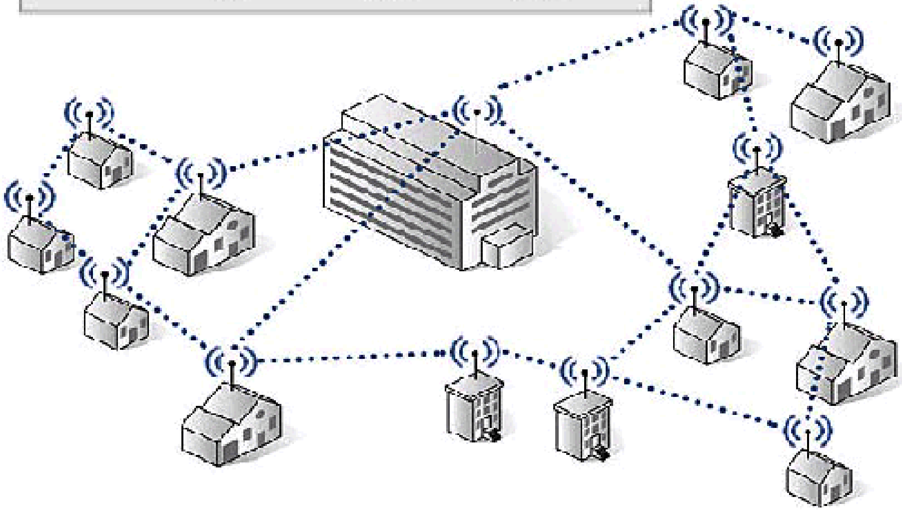
ETSI
IEEE WirelessMAN™ 802.16
intel.
NOKIA
ERICSSON
MOTOROLA

TOSHIBA
TDD Coalition

TDD Advantages – MOTIVATION!

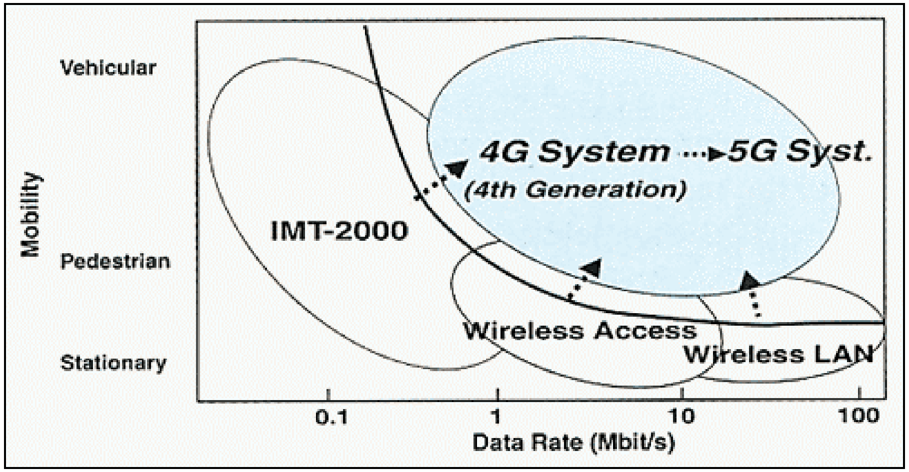


- Flexibility with traffic asymmetry
- Efficiency / cost / simplicity
- Dynamic resource allocations
- Channel reciprocity
- Innovations and signal processing
  - Time-space processing
  - Downlink processing
  - Smart antenna
  - Power control management
  - Adaptive modulation / frame boundary
- Dynamic topology – MESH
  - Self-organizing network
- Internet services



Worldwide TDD Deployments

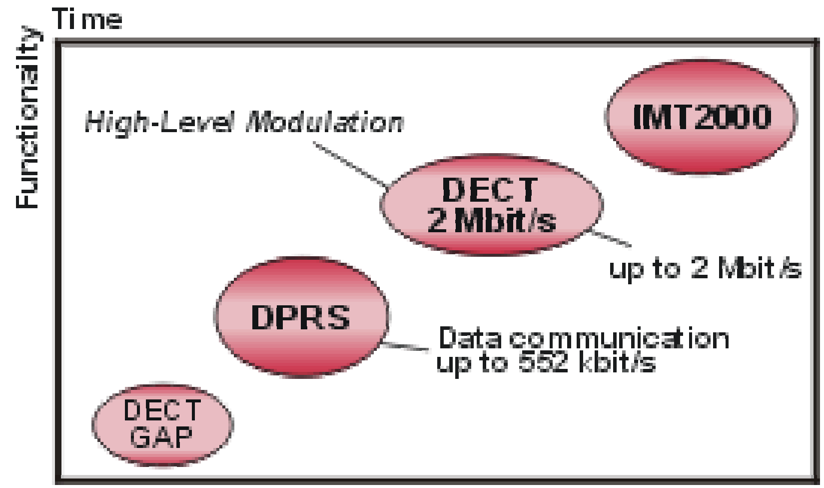
- **Mobile environment**
  - DECT (Digital Enhanced Cordless Telecommunications – Europe)
  - CT2 (cordless Telephone)
  - PHS (Personal Handyphone System – Japan)
  - 3GPP: UTRA-TDD mode
- **Fixed environment - WMAN**
  - IEEE802.16 (PMP systems in 10-66 GHz range)
  - IEEE802.16ab (systems in 2-11 GHz range)
  - HIPERACCESS (PMP systems – Europe)
- **Fixed environment – WLAN / WPAN**
  - IEEE802.11 (USA)
  - HIPERLAN (Europe)
  - MMAC
  - Bluetooth
  - Home RF



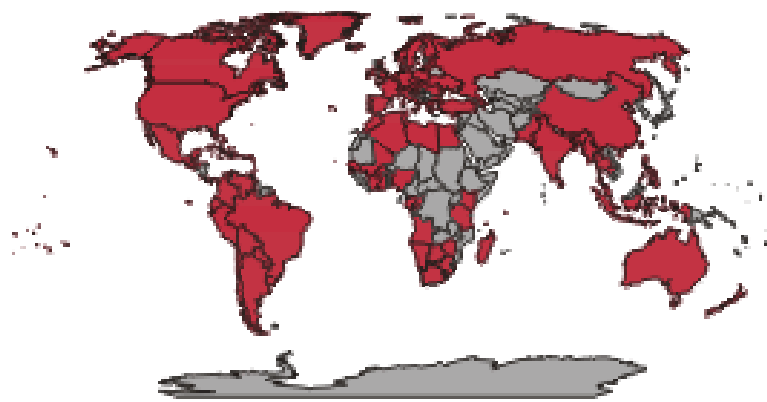
TDD – Digital Cordless Telephones

Digital Cordless Telephones			
Standard	**CT2/CT2+** **Cordless Telephone 2**	**DECT** **Digital Enhanced Cordless Telephone**	**PHS** **Personal Handy Phone System**
Mobile Frequency Range (MHz)	CT2: 864/868 CT2+: 944/948	1880-1900	1895-1918
Multiple Access Method	TDMA/FDM	TDMA/FDM	TDMA/FDM
Duplex Method	TDD	TDD	TDD
Number of Channels	40	10 (12 users/chanel)	300 (4 users/channel)
Channel Spacing	100 kHz	1.728 MHz	300 kHz
Modulation	GFSK (0.5 Gaussian Filter)	GFSK (0.5 Gaussian Filter)	π/4 DQPSK
Channel Bit Rate	72 kb/s	1.152 Mb/s	384 kb/s

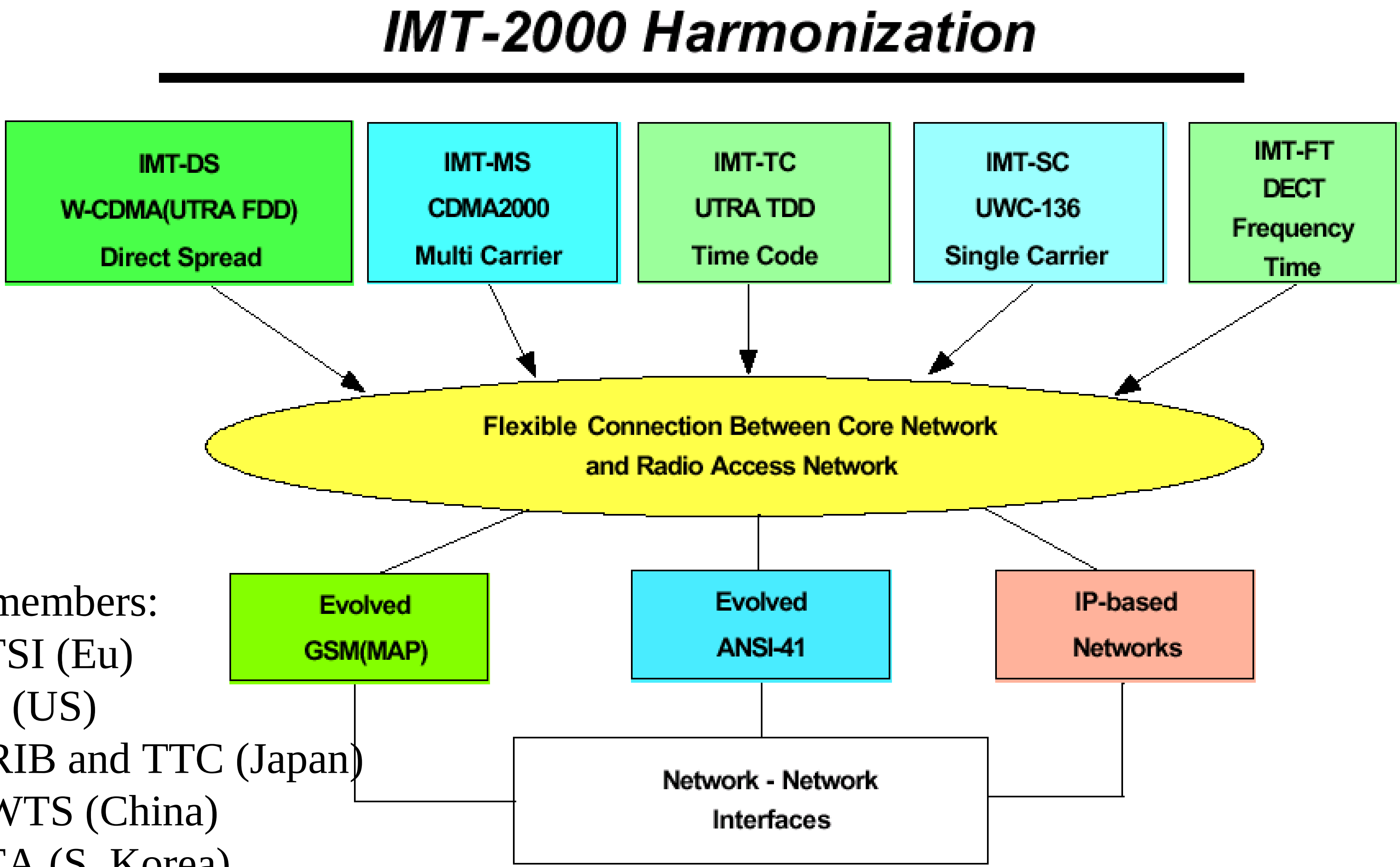
DECT/PHS



- **TDD and TDMA**
- **Efficient use of spectrum and high user density**
- **Voice and data services supported**
  - DECT GAP
  - DPRS (up to 552kbit/s)
  - DECT 2Mbit/s
  - IMT2000 migration path
- **Miniaturization**
  - Small, light, low cost devices are feasible
  - PHS has been used for animal tracking



IMT-2000 Modes



- 3GPP members:
  - ETSI (Eu)
  - T1 (US)
  - ARIB and TTC (Japan)
  - CWTS (China)
  - TTA (S. Korea)

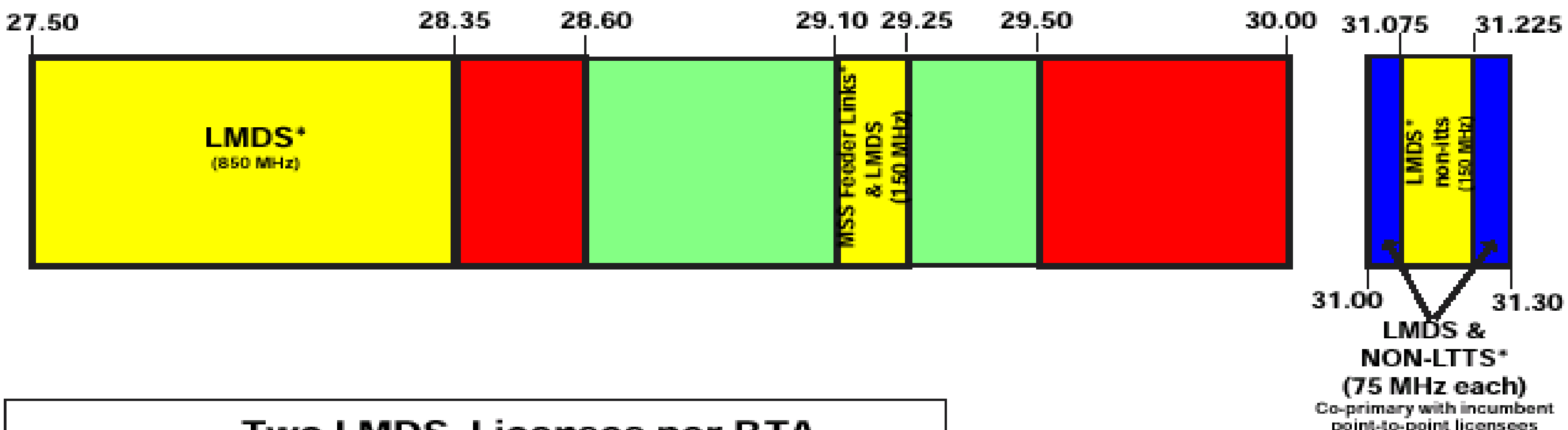
UTRA - TDD

- Accepted IMT-2000 Standard (ITU-TC), meets ITU requirements for 3G data speeds – 3GPP
- TDD systems benefits:
  - **Downlink processing, smart antenna, space-time processing, …**
- Technology consists of W-CDMA air interface coupled with GSM-compatible core network to allow equipment sharing with GSM/GPRS and UTRA-FDD networks
- Standard chip rate of 3.84 Mcps, 2X chip rate in future standard release
- Standard channel BW of 5 MHz is compatible with 6 MHz MMDS chann.
- Frequency allocation for UTRA-TDD: 1900 – 1920 MHz, 2010 – 2025 MHz in Europe
- WRC2000 allocated an IMT-2000 expansion band from 2500 – 2690 MHz, TDD allocation being considered across Europe for this band

Frequencies – Fixed Wireless

LMDS Band Allocation
(Local Multipoint Distribution Service)

28 & 31 GHz Band Plan



Two LMDS Licenses per BTA

Block A - 1150 MHz:	Block B - 150 MHz:
27,500-28,350 MHz	31,000-31,075 MHz
29,100-29,250 MHz	31,225-31,300 MHz
31,075-31,225 MHz	

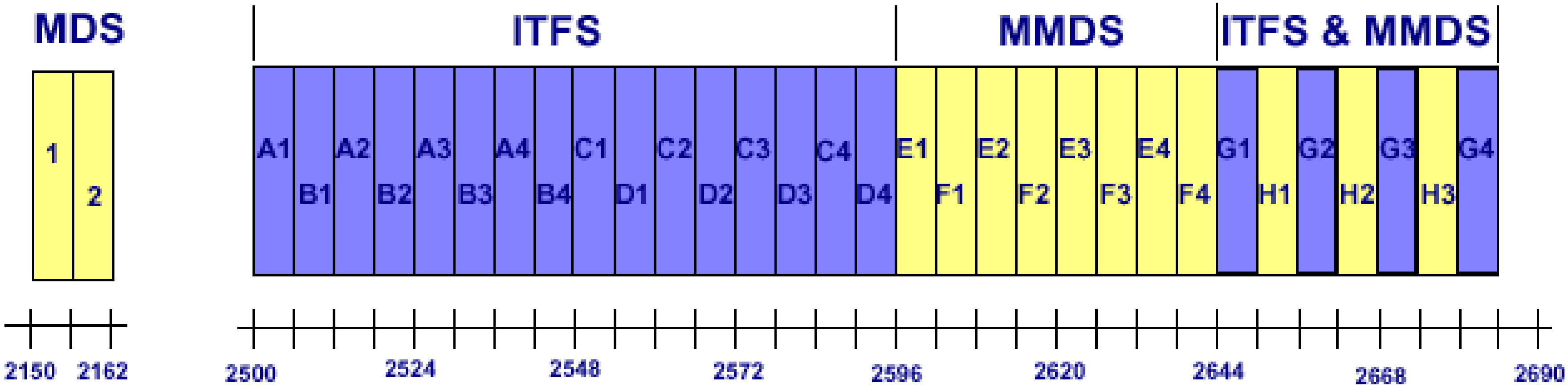
Legend

"*" - Primary Service
MSS - Mobile Satellite Service
NON-LTTS - Non-Local Television Transmission Service

Source: Federal Communications Commission

Frequencies – Fixed Wireless

Federal Communications Commission



<u>Congressional Federal Register References</u>

ITFS	47 C.F.R., Part 74
MDS (Single And Multichannel)	47 C.F.R., Part 21

Channel 2A: 2156-2160 MHz

2160-2162 MHZ reallocated to emerging technologies on a primary basis except for licenses operating on Channel 2, or successful applicants who filed prior to January 16, 1992. See ET Docket 92-9 FCC 93-351

MDS (Multipoint Distribution Service)
MMDS (Multichannel Multipoint Distribution Service)
ITFS (Instructional Television Fixed Service)

Service	Channel Allocation	Number of Channels
MDS & MMDS	1 & 2	2
	E, F & H	11

Not Included in Auction #6

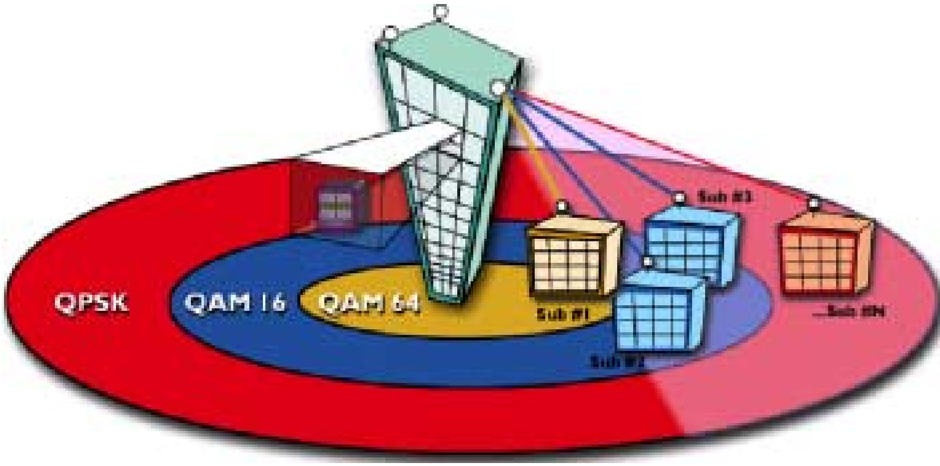
Service	Channel Allocation	Number of Channels
ITFS	A, B, C, D & F	20

FBWA - IEEE802.16

- **Air interface (PHYs with common MAC)**
  - P802.16: 10-66 GHz
  - P802.16a
    - 2-11 GHz: Licensed bands only
    - 5-6 GHz: Licensed-exempt – “ WirelessHUMAN™”
  - IEEE 802.16.2 (10-66 GHz)
  - P802.16.2a: amendment to 2-11 GHz

FBWA - IEEE802.16

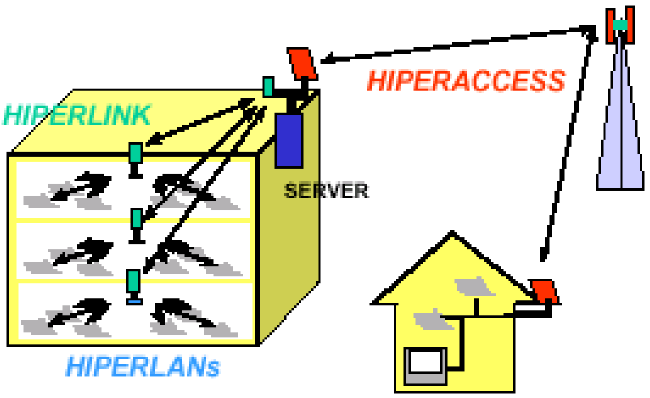
- **Scope**
  - Specifications for PHY and MAC for broadband wireless access for data rates of above 30 Mbps.
  - Licensed band: 10-66 GHz
- **Oriented toward**
  - Business services, Wireless Internet
- **Air interface standard**
  - PHY and MAC development
  - Subscriber station and base station
  - mmw frequency range
  - LMDS focus / LOS
  - Continuous and burst traffic
  - Efficient use of spectrum
  - Adaptive modulation



FBWA - IEEE802.16a

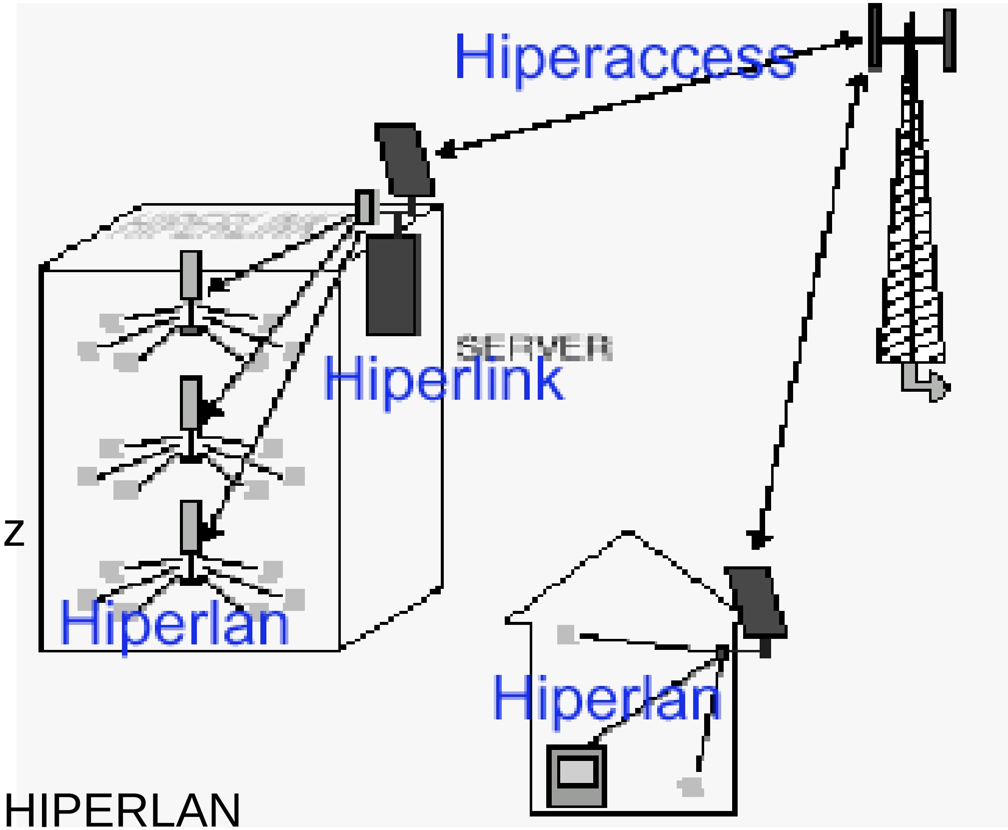
- **Scope**
  - Specifications for PHY and MAC layers for air interface of broadband wireless access systems in:
    - Licensed band 2-11 GHz: 2.5-2.7 GHz (US), 3.5 and 10.5 GHz (WW)
    - License-exempt band 5-6 GHz
- **Oriented toward**
  - Residential, small offices, telecommuters, small-to-medium enterprise markets – MMDS
  - Optional topology
    - Mesh operation
      - Subscriber-to-subscriber communications
- **Air interface standard**
  - OFDM (TDMA / OFDMA), SC-DFE
  - CLOS / NLOS
  - Antenna diversity

FBWA - HIPERACCESS



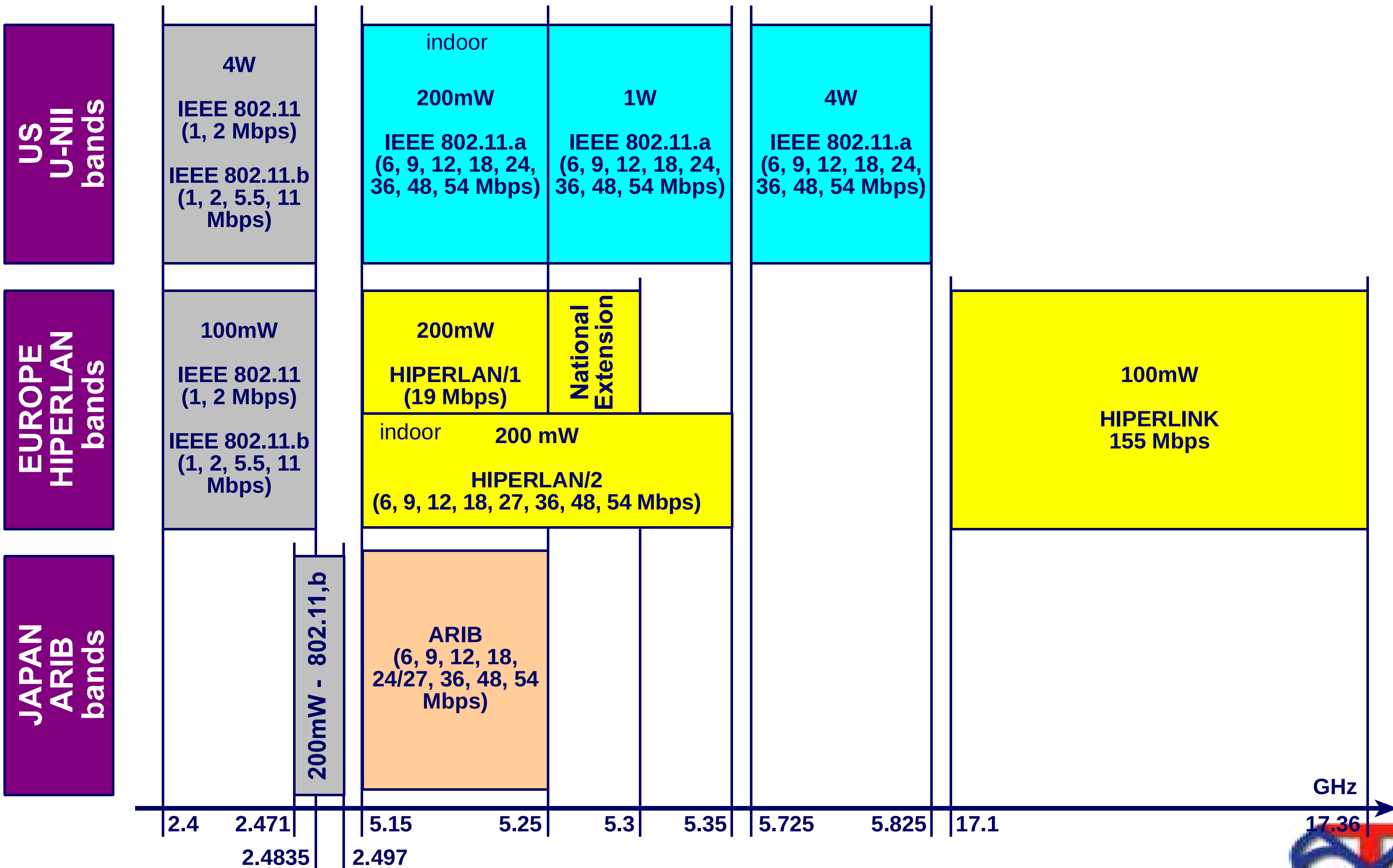
- **Scope**
  - PHY and MAC interface specifications for licensed high-frequency range 11-40 Ghz
- **Oriented toward**
  - UMTS backhaul, PMP
  - Symmetric / asymmetric, Internet, vedio
  - Outdoor usage for residential and SME applications up to 5 Km
- **Air interface standard**
  - Operating at 25 Mbps, (chann: 7, 14, 28, 56 MHz)
  - Providing long range and fixed radio connections to customer premises
  - Mainly licensed (>11 GHz, 40 GHz) and may be used for licensed-exempt (5 GHz)
  - TDD / FDD – BS (FD), SS (HD)

ETSI BRAN: Wireless Broadband Access



- **HIPERLAN/2 – 54 Mbps**
  - Short range, “cordless”
  - Up to 200 m
  - Indoor / Campus
  - License-exempt
  - Mobility
- **HIPERACCESS – 25 Mbps**
  - Long range, up to 5 Km / 40 GHz
  - Licensed and license-exempt
  - Residential, SME
- **HIPERLINK – 155 Mbps**
  - Interconnect HIPERACCESS & HIPERLAN
  - Up to 150 m / 17 GHz / P-P
  - Not started

High Performance Radio Bands



WLAN - HIPERLAN/2

- **Scope**
  - Specifications for PHY and MAC layers for air interface in license-exempt band 5-6 GHz supporting both fixed and mobile services for high-speed multimedia communications between different broadband core networks and mobile terminals.
- **Oriented toward**
  - Wireless access and WLAN, business and home multimedia
- **Air interface standard**
  - Up to 54 Mbps in 5 GHz band
  - OFDM / 52 carrier, 20 MHz channel
  - Centralized and direct modes
  - Short range and cordless services
  - Indoor coverage of 50 m and outdoor of 150 m
  - **TDD – low round trip**

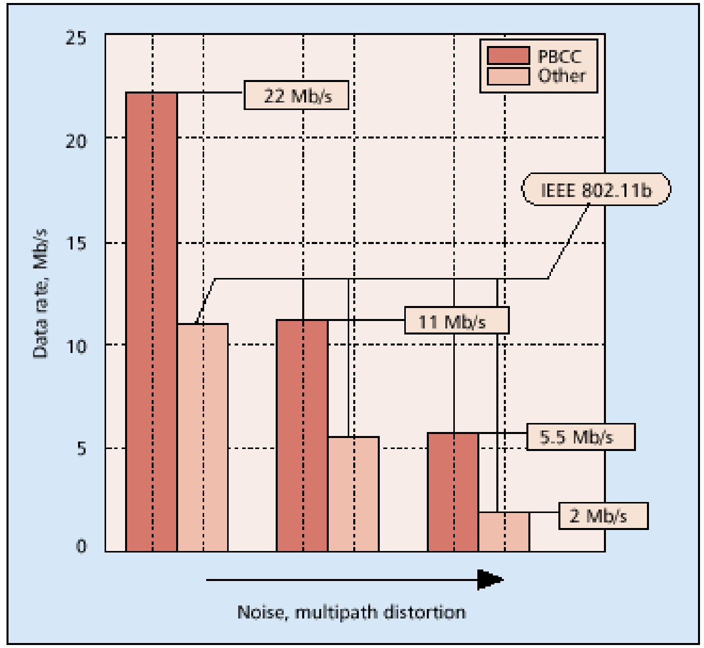
WLAN – IEEE802.11 Family

IEEE802.11 FH/DS

IEEE802.11a

HIPERLAN2

IEEE802.11g (PBCC)



IEEE802.11b (Wi-Fi)

IEEE802.11g (OFDM)

MMAC (HiSWANa)

Standard	Modulation & Coding[2]	Spectrum Unification	Available Spectrum	Data Rate[3]	Throughput	Range[4] & Corresponding Data Rate
Wi-Fi	DSSS / CCK	Yes	83.5 MHz	11 Mbps	5-7 Mbps	100 m[4] @ 11 Mbps
$802.11g_{OFDM}$	OFDM	Yes	83.5 MHz	24 Mbps[3]	10-11 Mbps	100 m[4] @ 12 Mbps
$802.11g_{PBCC}$	DSSS / PBCC	Yes	83.5 MHz	22 Mbps	10-11 Mbps	100 m[4] @ 11 Mbps
802.11a	OFDM	No	300 MHz	54 Mbps	31 Mbps	50 m[4] @ 9 Mbps

WLAN – IEEE802.11/b

- **Scope**
  - Specifications for PHY and MAC layers for air interface in license-exempt band 2.4 GHz (ISM)
- **Oriented toward**
  - Residential / business, SOHO
- **Air interface standard**
  - Wi-Fi (IEEE802.11b) + IEEE802.11g
    - WLAN, Wireless Ethernet
    - DSSS, D-B/QPSK, CCK 1/2/5.5/11/20+ Mbps
    - FHSS, 79 channels, GFSK, < 2 Mbps, < 1W

WLAN – IEEE802.11a

- **Scope**
  - Specifications for PHY and MAC layers for air interface in license-exempt band 5-6 GHz (U-NII)
- **Oriented toward**
  - Wireless multimedia, SME
- **Air interface standard**
  - OFDM based, MQAM (M=2,4,16, 64)
  - Channel spacing 20 MHz, 6-54 Mbps, U-NII
  - 52 carriers (48D, 4P)

Bluetooth (IEEE802.15)

- **Technical specs.:**
  - TDD 625 msec
  - Slow FH 1600h/s
  - ISM band 2.4 GHz, small form factor, low cost
  - 79 RF channels @ 1 Mbps (23 in Japan, France, and Spain)
  - GFSK, $m \leq 0.35$
  - Short range: 10-100m, piconet
  - Symmetric 185.6 kbps / Asymmetric 721 kbps
  - PP, PMP, and MPMP connections
  - High-bit rate, 22-55 Mbps (IEEE802.15.3)

- **Applications / Markets**
  - Voice data access point
  - Cable replacement
  - Personal ad hoc network

TDD Systems

- **FBWA:**
  - IEEE and ETSI specify TDD options. The full range of voice and data services is supported.
  - Some legacy frequency plans are “FDD” (such as CEPT T/R 13-02). Several manufacturers believe TDD is not only feasible but preferable, even in these “FDD” bands.
  - “Mesh” systems use TDD for flexibility. It is the most logical and best choice.
  - IEEE/CEPT (ERC/RA) has also published a “recommended practice” companion document to the .16 standard, showing that TDD and FDD can easily coexist.
- **WLAN**
  - Extensive range of voice and data services supported
  - “…implements a form of dynamic time division duplex to allow for *most efficient utilization of radio resources*”. (Hiperlan2 Global Forum)

What do these examples show?

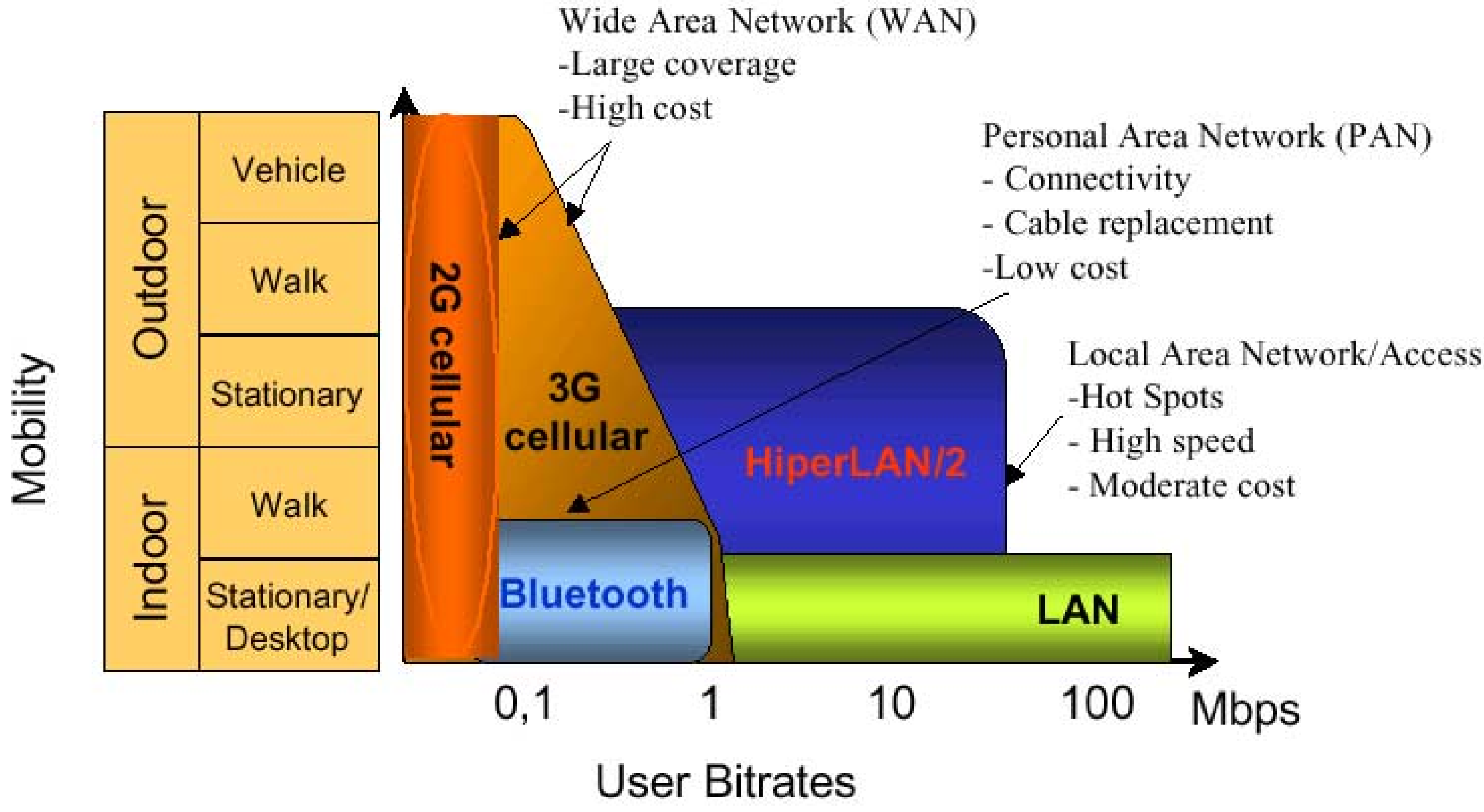
- **TDD is well-suited for 3G enhancements**
  - Speed and efficiency
  - Spectrum shortage (US carriers)
- **TDD works across the entire range of frequencies**
- **TDD provides efficient and usually better use of spectrum**
- **All the required voice, data and related services can be supported**
- **TDD works with high density of users and base stations (1000 Erlang/km^2/floor in DECT)**
- **It is consistent with low-cost, small and lightweight products. You can even track racoons and crows….!**

Broadband Technology Trends

- **Air interface**
  - Adaptive TDD/smart technology, flexibility in resource allocation
  - Adaptive burst profile (modulation+FEC), ATPC (TDD)
- **Network architecture**
  - Mesh systems, multi-hop, self-organizing, dynamic topology (TDD)
  - Multi-layer hierarchy, VPN
  - Macro- to micro/pico- cell technology (more suited for TDD) – “hot spots”, airport, metropolitan, shopping centers, …
- **Wireless environment**
  - Efficient use of spectrum (TDD)
  - BW on demand, dynamic asymmetric BW allocation (TDD)
  - Convergence of BW access and BW mobile
- **Broadband services**
  - Context aware, Internet on air, mobile IP, full QoS, security, VoIP
  - High data rates: from <2 Mbps to >155 Mbps

BACKUP SLIDES

Wireless "Data" Solution



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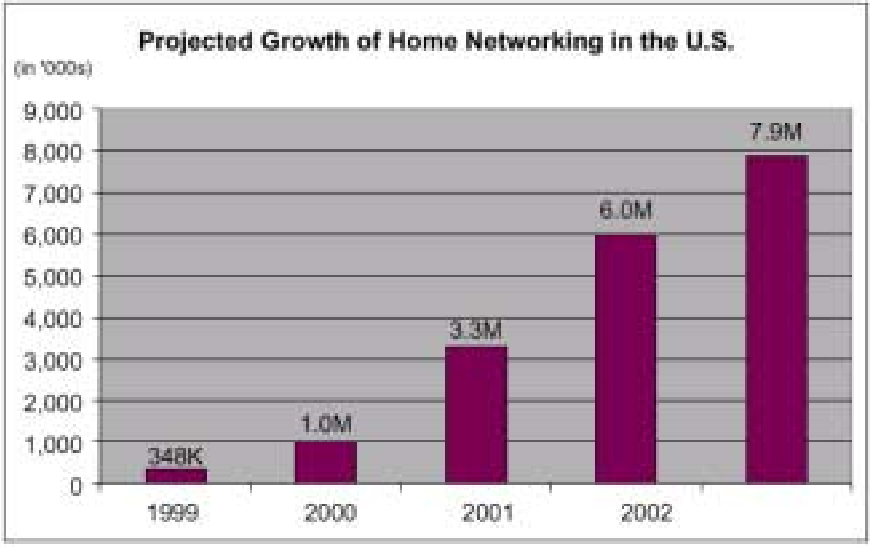
Home RF

- **Technical spec.:**
  - TDD technology
  - 2.4 GHz, up to 150 feet, FHSS
  - Data rate:10 Mbps (20 Mbps in future)
  - Low power
- **Applications / Market:**
  - Home networking, small business, SOHO
  - Avoids rewiring homes, portability, access sharing
  - Supports DECT
  - Enhanced Telephone features
  - Integrated voice and data



Source: Dataquest (March 2000)

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Part 3: Spectrum Allocation and Coexistence Issues

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Outline

- TDD-FDD Coexistence
- TDD-FDD Collocation
- General Rules & Practices
- Mitigation Techniques
- Efficient Spectrum Allocations

TDD-FDD Coexistence

TDD & FDD Coexistence

IEEE 802.16.2 Recommended practices for coexistence:

1. A victim receiver should be 6dB below the receiver thermal noise
2. Each operator should take the initiative to collaborate with other known operators prior to initial deployment and at every relevant system modification
3. Each operator should design and deploy his own network for the maximum amount of frequency reuse
4. Incumbent / first movers should be given the same status as operators who deploy at a later time when resolving coexistence issues
5. No coordination is needed in a given direction if the transmitter is greater than 60km from either the service area boundary or the neighbor's boundary (60km no-coordination separation)

TDD & FDD Coexistence

6. Operators should use the trigger value of –114dBW/MHz/m^2 (24,26,28 GHz) and –111dBW/MHz/m^2 (38,42GHz) of the power spectral flux density at the boundaries when collaborating with neighbors.
7. Apply the triggers of Recommendation 5 and 6 prior to deployment and prior to each relevant system modification.
8. Deployment in the same area or in adjacent channel interference cases, the deployment will typically need one guard channel between nearby transmitters.
9. Utilize appropriate antennas for the base station and subscriber terminals (low side lobes and cross polarization).
10. Utilize appropriate emissions masks for the base station and subscriber terminals (low out-of-band emissions).
11. Minimize BTS and subscriber EIRP. Utilize BTS and subscriber power control.
12. Utilize the recommended approach to calculate the power spectral flux density at the boundaries.

TDD-FDD Collocation

TDD-FDD Collocation

Collocation of TDD & FDD systems are possible on the same tower with no performance degradation when an appropriate guard band is used.

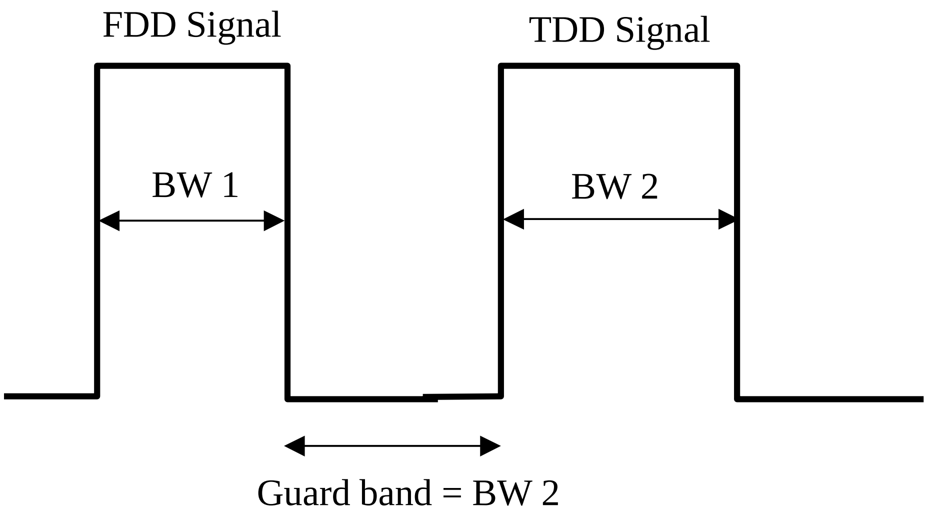
The required width of the guard band depends on the following factors:

- **Out-of-band emissions of the transmitters**
- **Performance of transmitter output filter**
- **Directional antenna performance (side lobe suppression)**
- **Polarization**
- **Antenna positioning (space separation and orientation)**
- **Receiver sensitivity**

General Rules & Practices

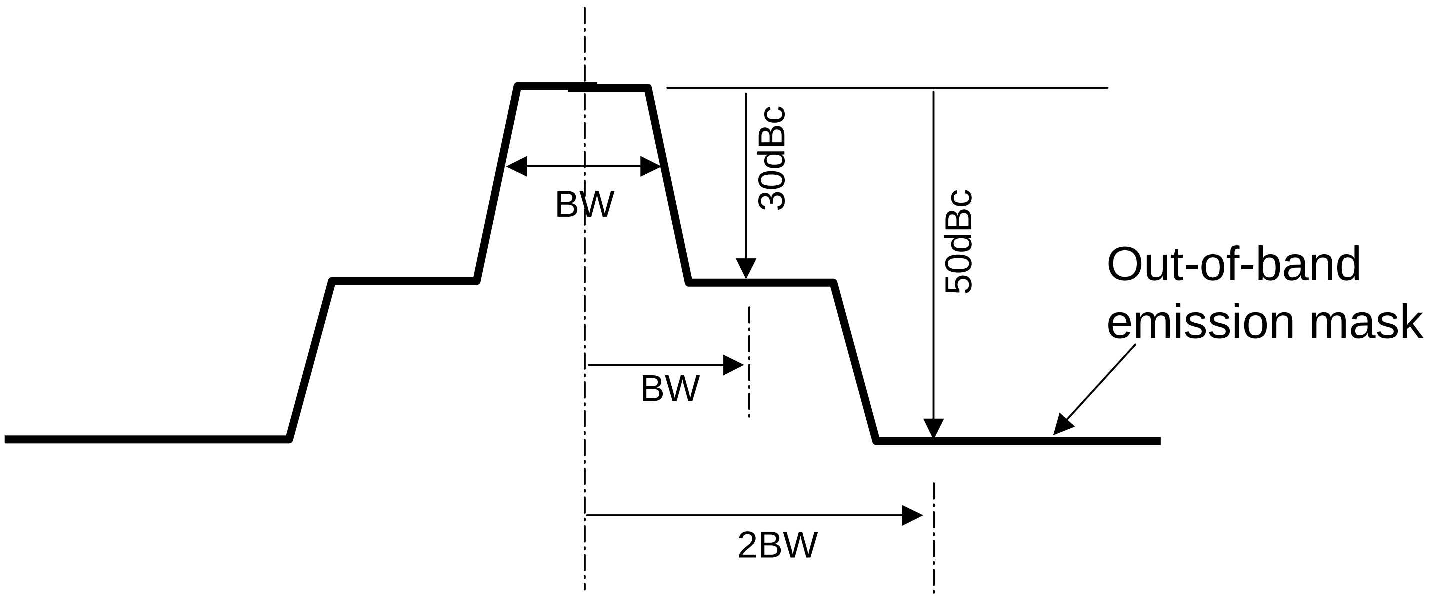
Guard Band

A typical guard band of a “single bandwidth channel” is required between an FDD and TDD systems. When the FDD & TDD transmissions are of different bandwidth, the guard band should be equal to the wider of the 2 channels.



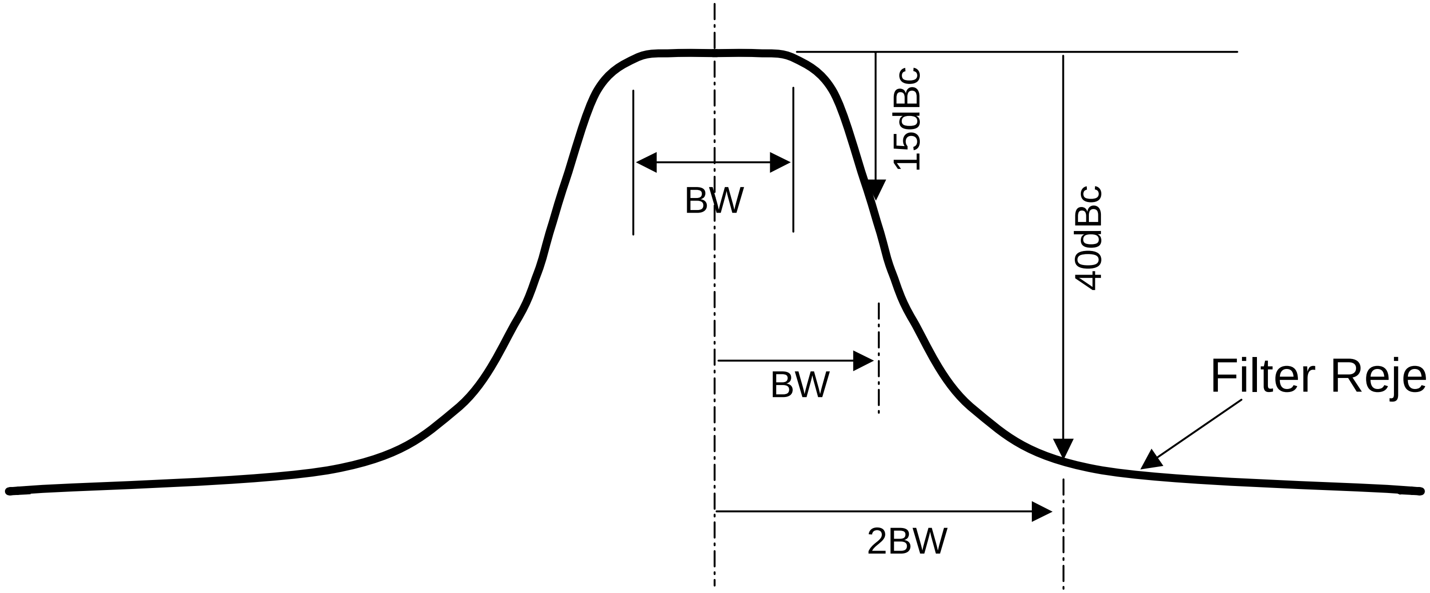
Out-Of-Band Emissions

Typical FDD and TDD transmitter out-of-band emissions are ~30dBc (~50dBc) below the channel power at one (two) signal bandwidth away from the channel center.



Transmitter Output Filter

A typical low cost pass band cavity filter can provide ~15dB (~40dB) rejection at one (two) bandwidth away from the pass band center.



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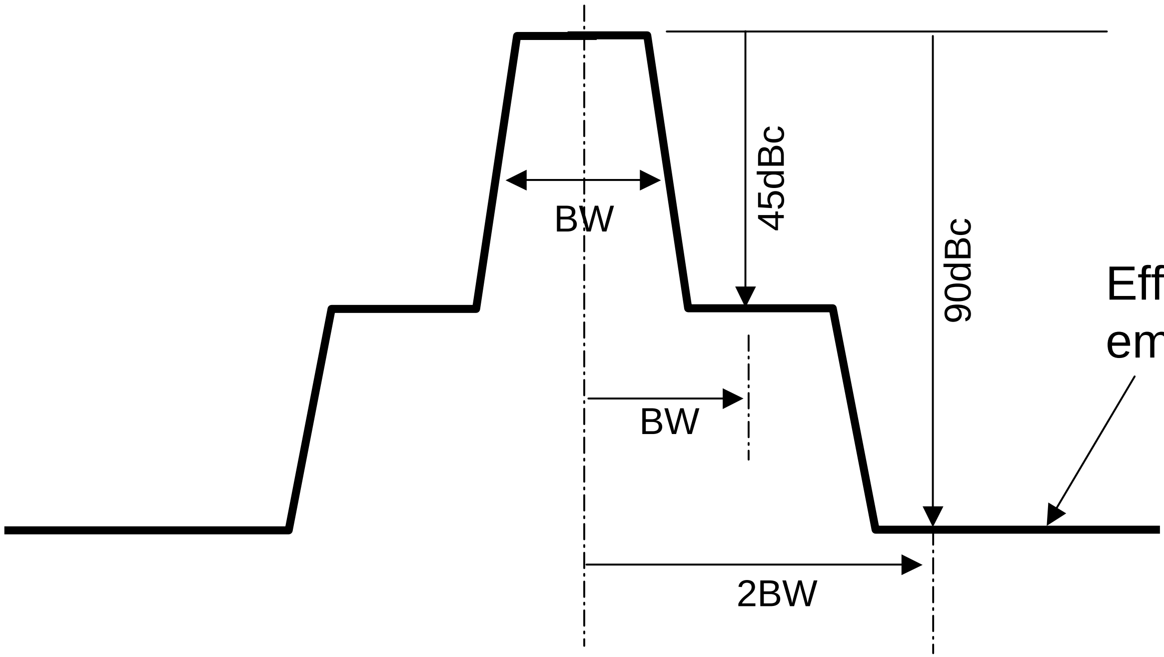
Effective Out-of-Band Emissions

Combine the transmitter out-of-band emission suppression and the transmitter output filter out-of-band rejection, the effective transmitter out-of-band emissions will be:



Antenna

- Directional antennas
  - **The side lobes should be at least 30dBc down from the main lobe peak at elevation and 10dBc at azimuth (at an angle of 90^{o} from the bore direction).**
- Omni-directional antennas
  - **The side lobes along the axis should be at least 20dBc down from the main lobe peak.**
- Polarization
  - **If possible, FDD and TDD systems should use different polarizations.**
  - **The cross polarization isolation is about 10~15dB.**
- Separation
  - **There should be a minimum of 10 ft separation between antennas for FDD and TDD systems.**
  - **The 10 ft (center to center) separation will have a 50dB isolation at 2GHz and 56dB at 5GHz and 67dB at 20GHz.**

Mitigation Techniques

Mitigation Techniques

Filters

- Interference among different systems can be suppressed by adding filters at both interfering transmitters and victim receivers.
- Adding filters at a transmitter to improve its out-of-band emission will reduce the adjacent channel interference.
- Adding filter at the receiver will improve receiver adjacent channel rejection.

Mitigation Techniques

Adaptive Antennas

- Adaptive antenna array can significantly reduce the interferences among different systems. This is accomplished in the following ways:
  - **Adaptive antenna array sends a signal only to the receiver that is intended for and not everywhere along all directions.**
  - **Adaptive antennas array can generate several null points at problem receivers and reduce the interference signal levels.**

Mitigation Techniques

Network Planning & Site Engineering

- Generally good practices for network planning and site engineering:
  - **Maximum frequency reuse**
  - **Minimize transmitter EIRP**
  - **Use different polarization in adjacent areas**
  - **Implement transmitter power control**
  - **Utilize antennas with low side lobes**

Interference Mitigation Example

- Two directional FDD & TDD transceivers that are located at the same tower with 10ft separation:

  Interference = 40 (Tx output power) + 18 (Tx antenna gain) + 18 (Rx antenna gain) – 50 (out of band mask) – 40 (cavity filter rejection) – 30 (Tx antenna side lobe suppression) – 30 (Rx antenna side lobe suppression) – 50 (antenna separation) = -124dBm

- If the the interference signal (as calculated above) is much less than the thermal noise then there is no interference problem.
  - **Assume the signal BW is 1MHZ**
  - **The thermal noise floor = -174 (power within 1Hz) + 60 (10log10E6) = -114dBm**
  - **Since -114dBm >> -124dBm there is no interference issue**

Efficient Spectrum Allocations

Efficient Spectrum Allocations

Contiguous allocation

- Contiguous spectrum allocations are preferred in order to harmonize FDD and TDD systems
  - **Any spectrum block can be segregated into four contiguous segments, FDD takes the low / high ends and TDD takes the middles, or *vice versa*, or FDD and TDD segments are interleaved.**
  - **Frequency partition allows for maximum utilization of spectrum and minimum cross interference between FDD and TDD systems.**
  - **In cases where the spectrum block is not wide enough to allow a guard band for FDD, the block shall be allocated for TDD only.**

Efficient Spectrum Allocations

Service Rules

- Power Limits:
  - **Power limits should be set based on the coverage and interference protection.**
  - **Higher power will have wider coverage but cause more interference.**
  - **Carriers should use only the minimum EIRP for their coverage area.**
- Reuse:
  - **Maximum reuse of frequency will increase efficiency and reduce interference.**

Efficient Spectrum Allocations

Service Rules

- Number of licensee:
  - If only using a TDD system, the entire spectrum can be segregated into two contiguous blocks, one for carrier A, the other for carrier B.
  - If using both FDD & TDD systems, the spectrum can be segregated into four contiguous blocks. Two blocks for FDD and two blocks for TDD. FDD takes the low / high ends and TDD takes the middles, or *vice versa*, or FDD and TDD blocks are interleaved.
- Spectral mask:
  - Requirements for spectral mask will determine the cost of transmitters and width of the guard band.
  - As the rule of thumb, the mask should roll off at lest 30dBc at one BW away from the channel center and 50dBc two BWs away from the center.

Backup Slides

Interference Example

- Two omni FDD & TDD transceivers that are stacked along the vertical direction with 10ft separation:

  Interference = 40 (Tx output power) + 10 (Tx antenna gain) + 10 (Rx antenna gain) – 50 (out of band mask) – 40 (cavity filter rejection) – 20 (Tx antenna side lobe suppression) – 20 (Rx antenna side lobe suppression) – 50 (antenna separation) = -120dBm

- If the the interference signal (as calculated above) is much less than the thermal noise then there is no interference problem.
  - **Assume the signal BW is 1MHZ**
  - **The thermal noise floor = -174 (power within 1Hz) + 60 (10log10E6) = -114dBm**
  - **Since -114dBm >> -120dBm there is no interference issue**

Interference Example

- A directional FDD & omni-directional TDD transceivers that are stacked along the vertical direction with 10ft separation:

  Interference = 40 (Tx output power) + 18 (Tx antenna gain) + 10 (Rx antenna gain) – 50 (out of band mask) – 40 (cavity filter rejection) – 30 (Tx antenna side lobe suppression) – 20 (Rx antenna side lobe suppression) – 50 (antenna separation) = -122dBm

- If the the interference signal (as calculated above) is much less than the thermal noise then there is no interference problem.
  - **Assume the signal BW is 1MHZ**
  - **The thermal noise floor = -174 (power within 1Hz) + 60 (10log10E6) = -114dBm**
  - **Since -114dBm >> -122dBm there is no interference issue**

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Tutorial on TDD Systems

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Monday, December 3, 2001

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Part 4: Advanced Technologies with TDD

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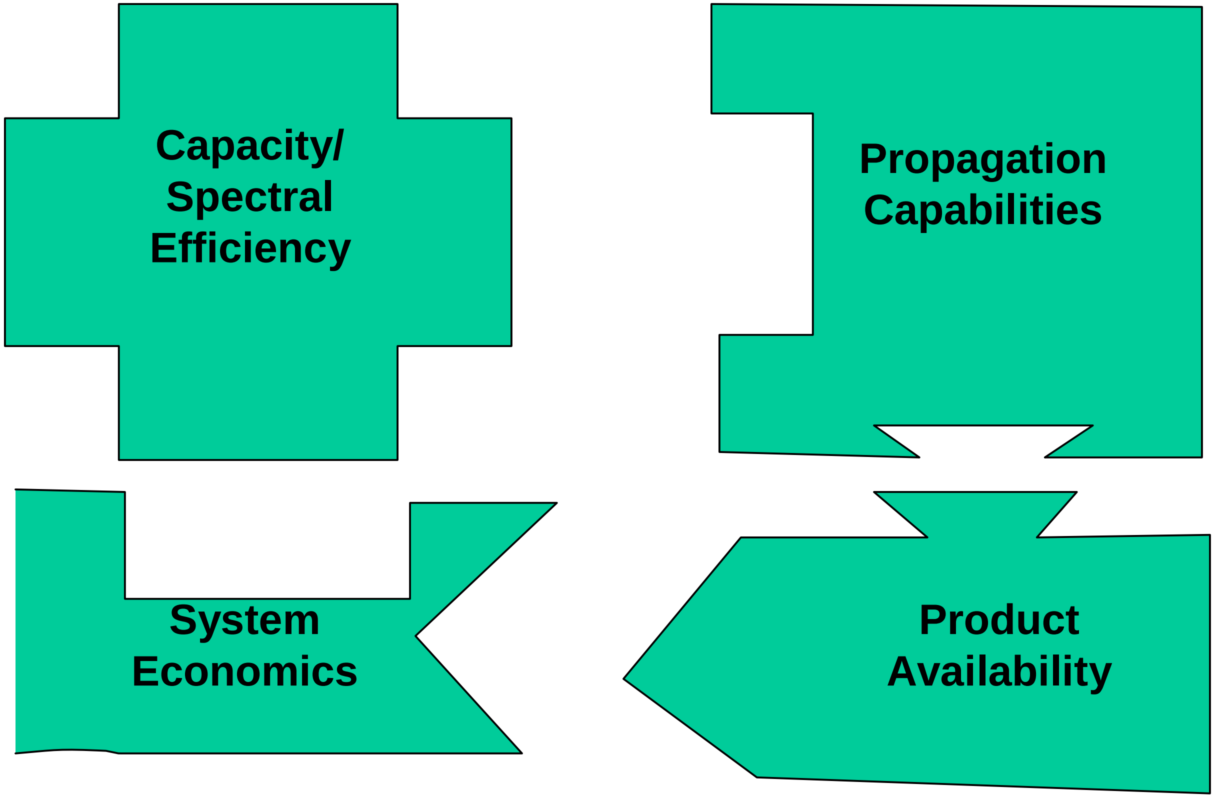
Finding the Answer for Broadband Wireless Access (BWA)

- High bits/Hz
- Support many BB subscribers
- High data rates

- NLOS
- Robust links
- Ease of Installation



- Low CPE cost
- Ease of installation
- Low infrastructure cost

- Would like the product ASAP

Operators still waiting for all the puzzle pieces to come together

Challenges Facing BWA Operators

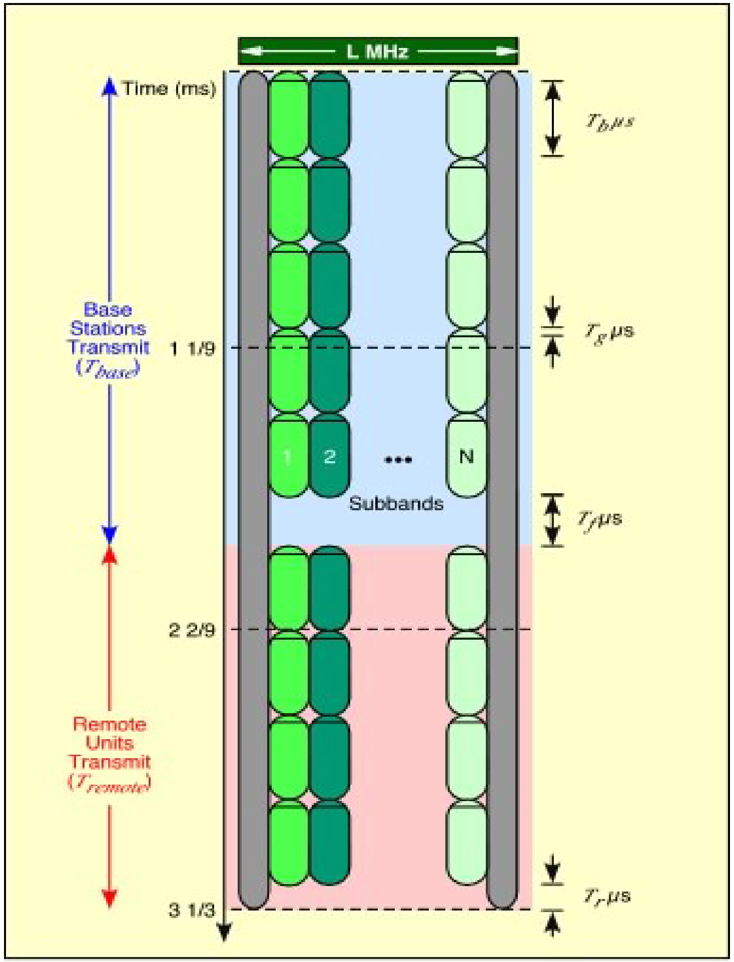
- **Cost of equipment**
- **Reliability of service**
- **Cost of spectrum**
- **Network interface**
- **Ease of installation**
- **Support large numbers of broadband subscribers**

- *Make the business case work!*

New innovative technologies are now being brought to market, many of them TDD-based, that can solve these dilemmas!

What is TDD, Time Division Duplexing?

- In TDD systems, each allocated channel can carry data upstream and down stream.
- Data is transferred in one direction. After a short transition guard band (typically 50-200 us), channel can transmit in opposite direction.
- Only small guard band required for inter-channel spacing.



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Benefits of TDD technology

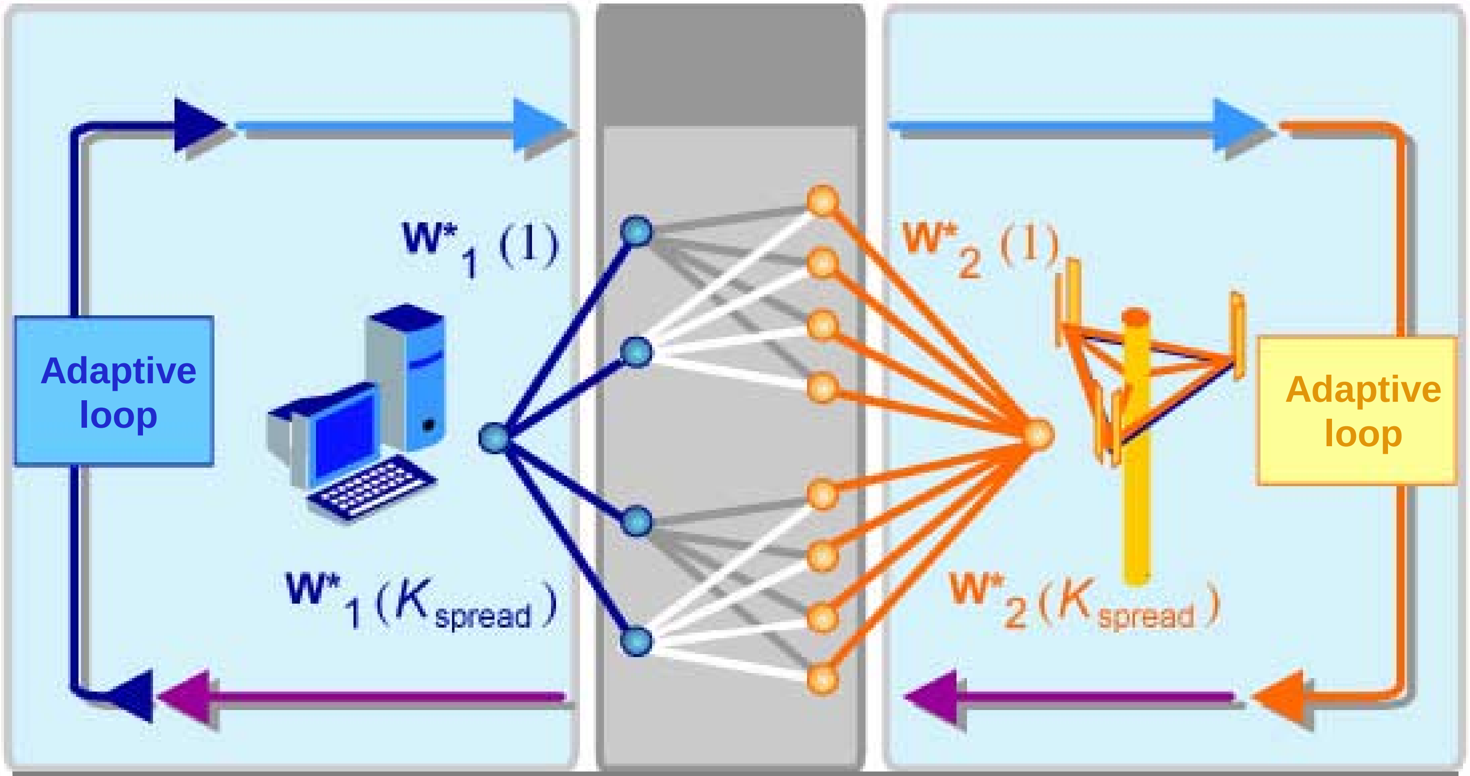
Benefits enabled by TDD

- Spectral Efficiency
- Reduced system costs
- Flexible Asymmetry

Technologies enabled by TDD

- Adaptive Antennas Arrays
- Mesh Networks
- Adaptive TDD

TDD Enables Adaptive Antenna Solutions

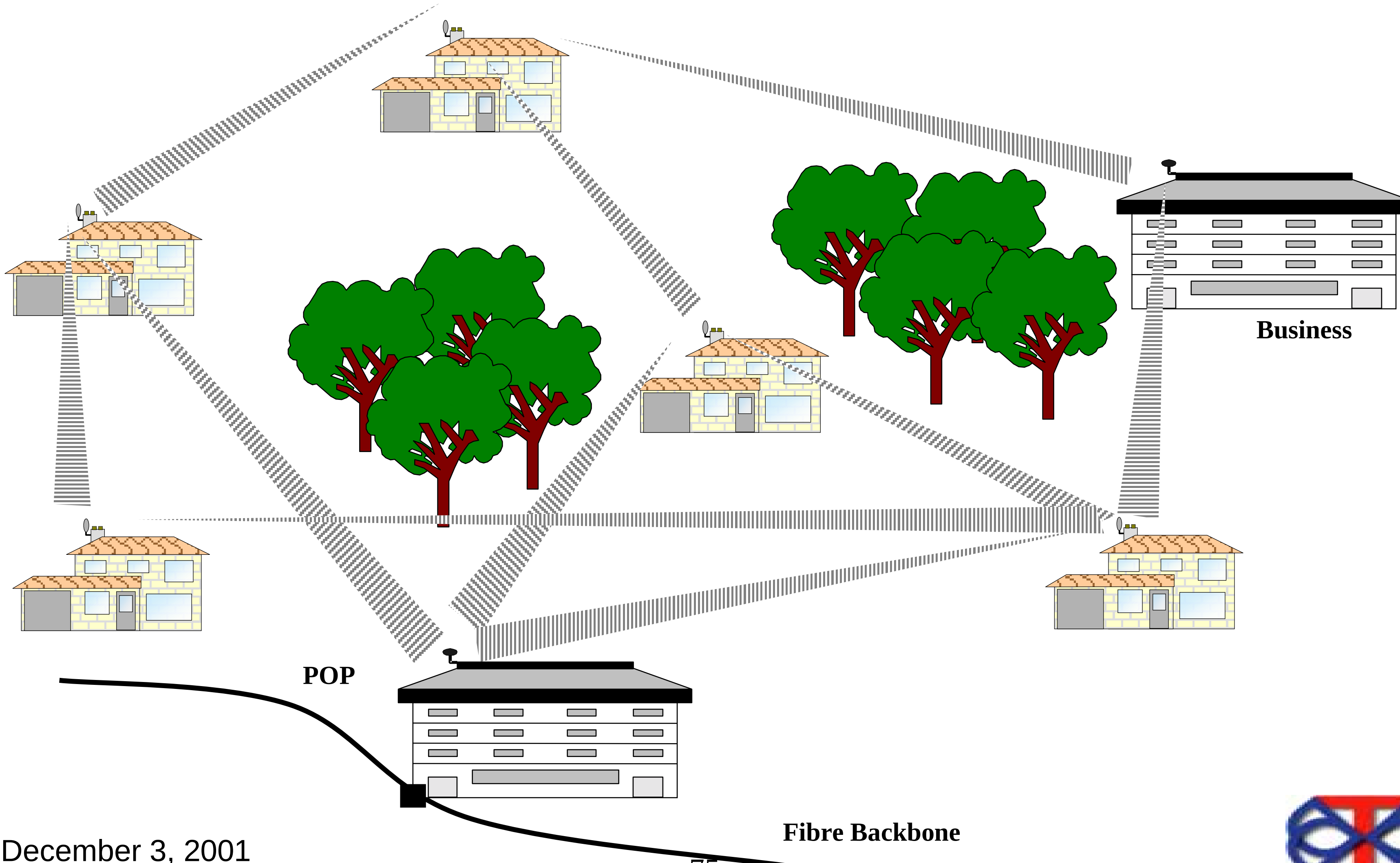


With TDD, the reciprocal nature of the RF channel increases spectral efficiency and coverage and improves economics

Benefits of TDD- Lower Costs

- Reduced radio component costs.
- TDD reduces filtering requirements, lowering system costs.
- System reciprocity allows reduction of CPE cost by keeping processing at base station.
- Simplifies frequency planning and power control.

TDD enables Mesh Networks



Advantages of TDD in a Mesh system

- Significant improvements in spectrum efficiency, coverage and coexistence.
- Allows complete and dynamic flexibility in uplink/downlink traffic (a)symmetry
- Improved coexistence by using time as a mechanism to avoid interference.
- Can work in paired or unpaired spectrum assignments
- By combining a mesh configuration with TDD, the coordination requirements are greatly reduced

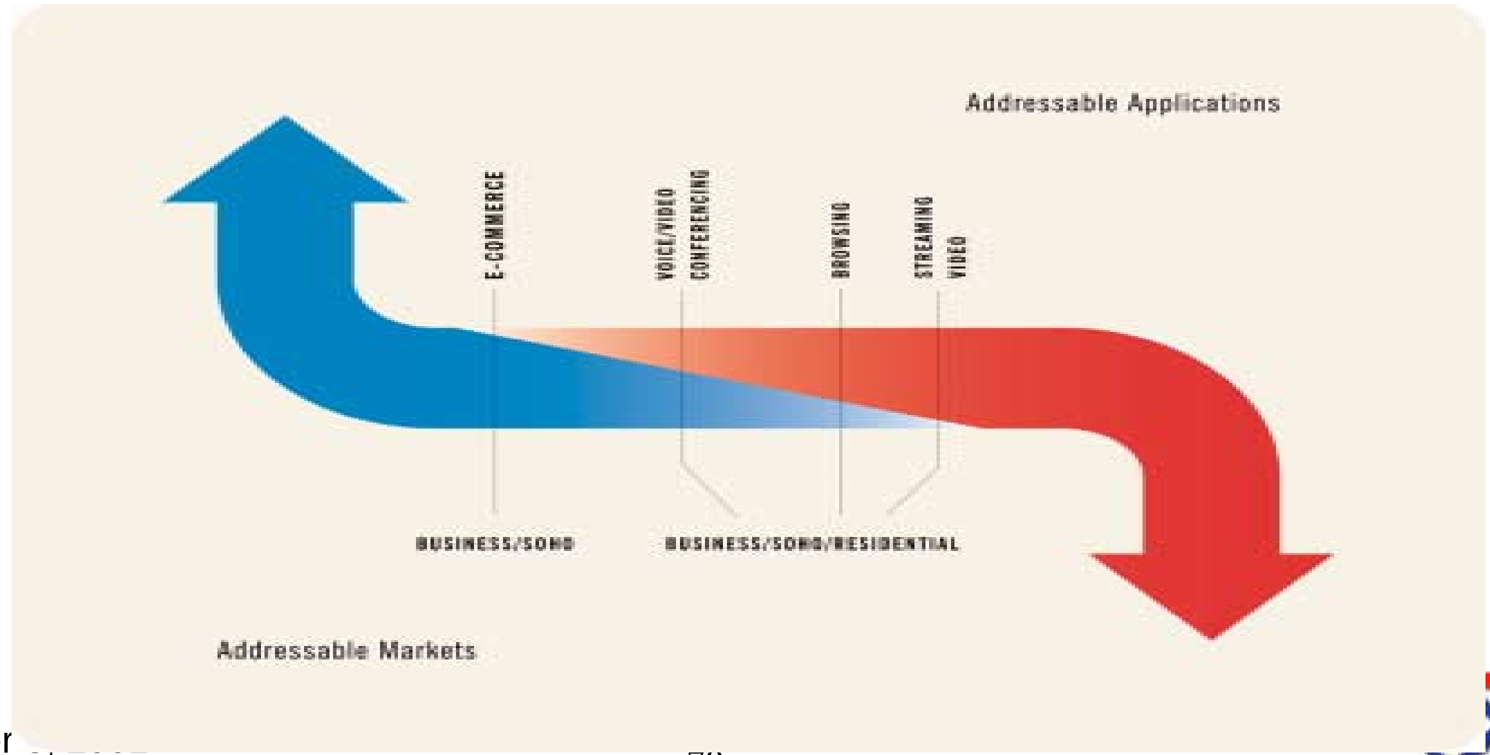
Adaptive TDD (Time Division Duplexing)

FDD

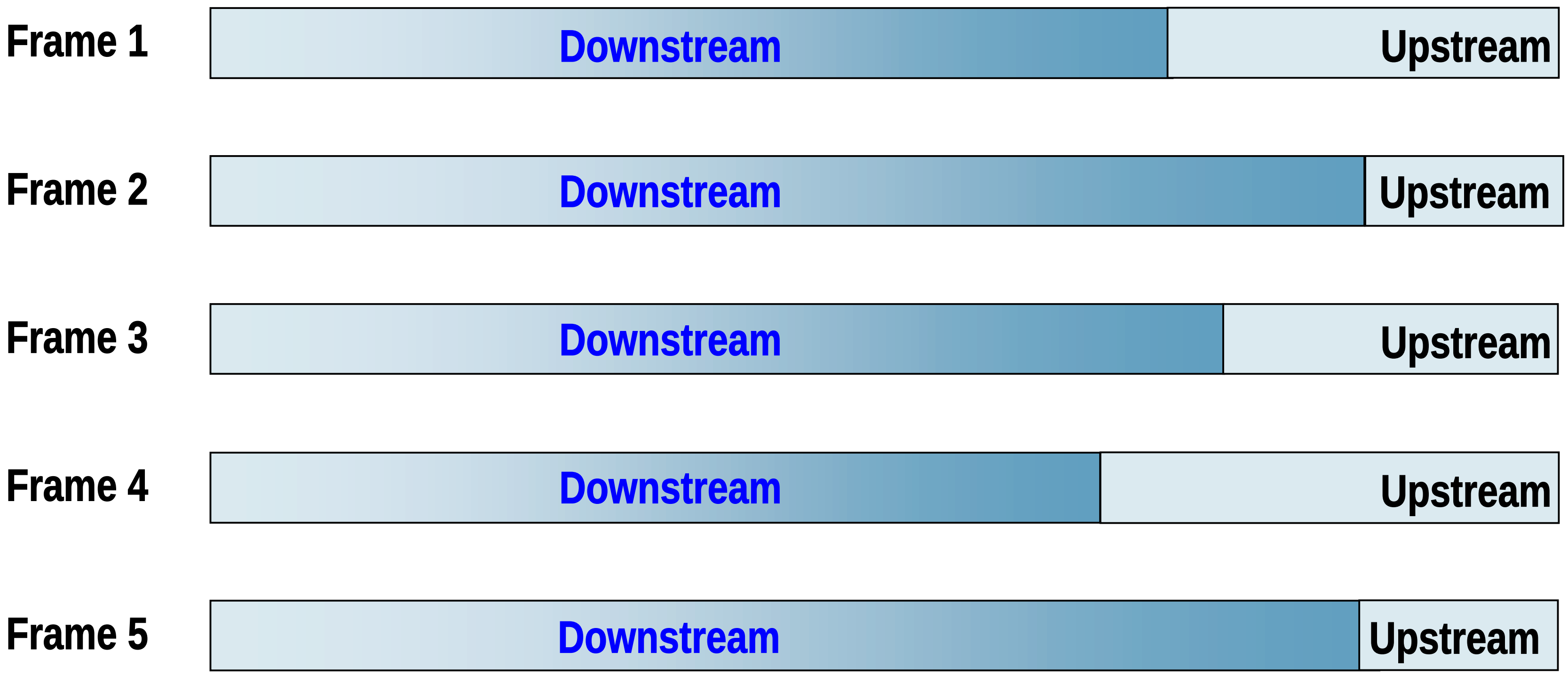
TDD

Benefits of TDD- Flexible Asymmetry

- TDD allows easy implementation of flexible asymmetry.
- Allows system to change symmetry "on the fly" by adjusting transmit/ receive time slot ratios.
- Future traffic requirements trend towards bursty data for both data and voice in IP-based networks.



Dynamic TDD: optimal, dynamic balance of upstream and downstream bandwidth



Bandwidth adjusts dynamically to meet user demand

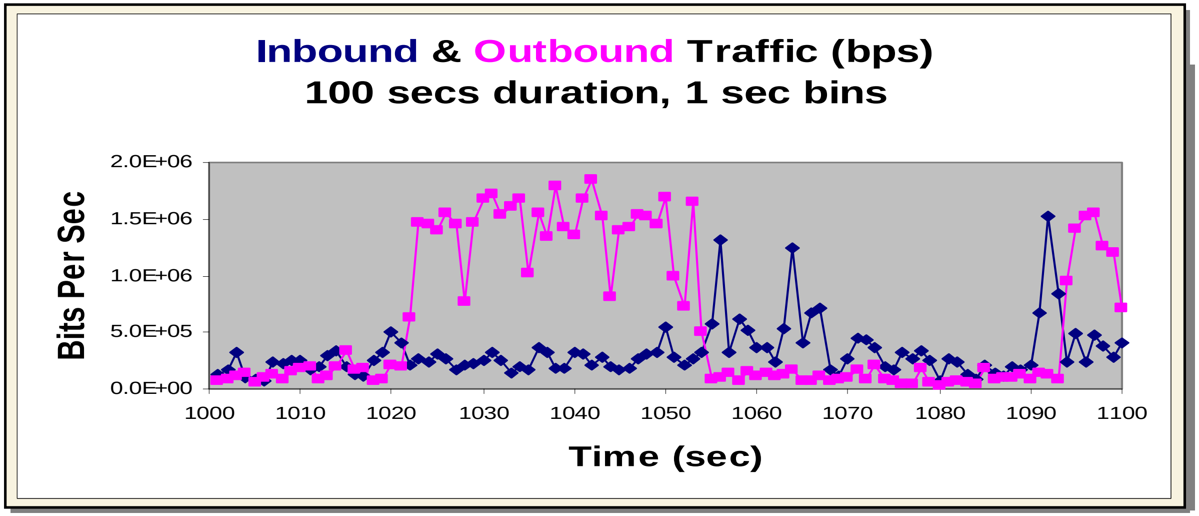
Adaptive TDD

LBL Traffic Variation vs. Time Scale (2)

LBL traffic is nearly symmetric averaged over 2 hours (53/47)

but

asymmetric over shorter intervals



Statistics Averaged Over 2 Hour Trace:
Aggregate: 392 kbps
Inbound: 185 kbps
Outbound: 207 kbps

Benefits of TDD- Spectral Efficiency

- TDD greatly reduces the need for inter-channel guard bands, increasing spectral efficiency.
- Allows system to change symmetry “on the fly”.
- Enables advanced techniques, such as mesh networks and adaptive antenna arrays.
- Effective for bursty, IP-based data. Can increase efficiency 60%.

TDD Innovations Conclusions

- **Many of today's innovative solutions that can solve operator's BWA dilemmas are using TDD technology**
- **TDD can be implemented in conjunction with other duplexing schemes, such as FDD, with only minor regulatory considerations.**
- **TDD systems can provide operators with superior system characteristics.**
  - Lower costs
  - Greater spectral efficiency
  - Flexible asymmetry

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Part 5: Opportunities and Technologies for Fixed TDD in the US

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Market Opportunities for TDD in the USA

- **Residential and SOHO Market Opportunity**
- **Small Medium Enterprise and Multi-Tenant Dwelling Market Opportunity**
- **The last 100 foot Opportunity (Wireless LAN)**
- **Additional TDD Spectrum**

Residential and SOHO Market

- Too Many Last Mile Wireless Business Plan have concentrated on Enterprise, medium, and large business customers
- Consider the Much larger Residential, SOHO, & SME Market
  - Only ~7% of Residential and SOHO POPS Have Broadband Access Today
  - The Bandwidth Divide
    - 30% to 50% of the US residential/SOHO/SME market does not have access to broadband internet services
  - 110 Million Residential and SOHO POPS in the US
    - A majority of the underserved are in Tier 2, 3 and 4 markets representing ~50% of the US population
    - Aggressive overbuilding in Tier 1 areas still leaves ~10% to 20% un-served

Broadband Wireless Access is the most cost-effective method to reach this market

The Total Available Market: Residential/SOHO

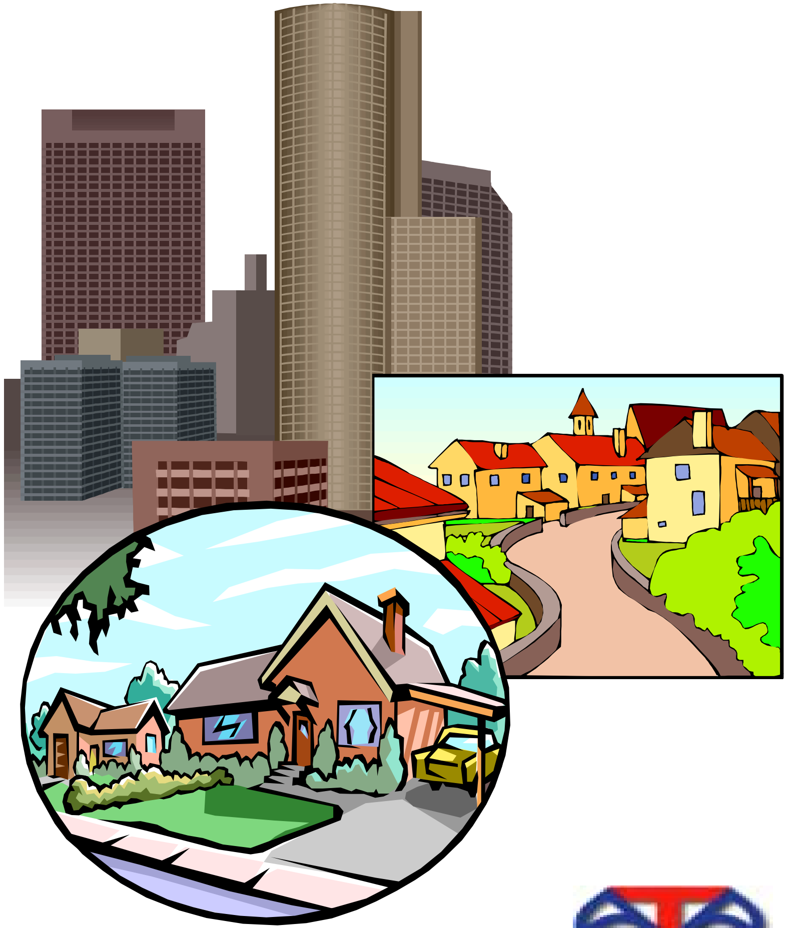
- Analysis based on latest census data
- The US market has ~110 million pops, Limit TAM to cities and counties that meet the following criteria:
  - Average household income > $25,000
  - Housing density greater than 230 homes/sq. [satellite for low density rural]
  - Conservative, 50 Sq Km cover per cell site coverage
  - TAM is limited to areas covered by cell that will be profitable with ~10% take rate of TAM

	Population	Average Household Income	Number of Markets	Addressable Homes
Tier 1	1,000,000+	$61,584	937	25,959,046
Tier 2	250,000+	$42,469	32	4,916,756
Tier 3	100,000+	$44,232	87	5,376,741
Tier 4	50,000+	$47,017	200	5,396,283
Tier 5	25,000+	$48,704	385	5,395,274
		Total:	**1,641**	**47,044,100**
		Tier 2, 3, 4, & 5 Total:	**704**	**21,085,054**

MTU/SME Market

■Multi-Tenant Units (MTU)

- ◆ Cluster homes with individual telecommunications connections (non-centralized wiring)
  - Duplex/Quadplex housing units
  - Row Homes
  - Miscellaneous cluster home configurations
- ◆ Small/Large apartments, with centralized wiring
- ◆ Landlord Controls Wire Access …



■Small/Medium Enterprise (SME)

- ◆ Business with ~8 to 100 employees
- ◆ Majority are in multi-story buildings
  - Roof access restrictions an issue
- ◆ Structured wiring (CAT 5 Data & Voice) available

SME & MTU Market Analysis

- **MTU market**
  - According to the latest Census Bureau data, approximately 27% of all households live in MTU's
  - Example: Onsite Access, a New York MTU Building LEC Operator
    - Achieved 100% penetration in the first building within the first year
    - Penetration rates 40% within the first three months after service is first offered
    - churn rates below 1%
    - However, due to the inability to gain access to a buildings risers and cable necessary at reasonable rates, often must rewire every building with fiber
- **SME market**
  - 750,000 commercial buildings in the US accommodating 7.4 Million businesses
  - Example: Hotels (Cahners In-Stat)
    - 73% of hotels are considering high-speed Internet for guest rooms
    - 82% of hotels with over 60% business clientele are considering
    - 48% of hotels surveyed plan to implement broadband in the next 12 months.
- **BFWA provides an essential low cost Last Mile Access delivery Method connect to these customer groups.**

MTU/SME Revenue Projections

- **MTU Market (Cahners In-Stat Group)**
  - MTU-related equipment sales will jump from $500 million in 2001 to $4 billion in 2005.
  - MTU broadband service and equipment sales will jump from $3.4 billion in 2000 to $8.5 billion in 2005, the high tech market research firm forecasts.
  - Many service providers offer remote and on-site network management and cable installation services.
- **SME Market**
  - SMEs comprise roughly 85% of U.S. business firms, 40% of employment, and one-third of the nation's economic output - but only about 6% of SMEs have broadband (Precursor Group)
  - 70% of these businesses are located in Multi-Tenant Units (MTUs)
  - 90% of those MTUs are under 200k SF, housing 2-20 tenants.
  - There are ~7 million small and mid-sized businesses in the United States. They are a key market for telecom service providers today. (Alcatel/Yankee Group)

WLAN: Solving the last 100 foot Problem

- **WLAN Market is based on successful IEEE 802.11 standards**
  - Deployed in ISM 2.4 GHz and 5.2/5.3 GHz un-licensed bands
  - IEEE 802.11b provides 11 Mbps in ISM band
  - IEEE 802.11g will extend .11b to 54 MBPS
  - Evolving 802.11a technology provides up to 54 Mbps in 5.x Band
- **WLAN is project to be a $4.6 Billion market by 2005**
  (Cahners In-Stat)
  - Individual subscribers will be sold in 10’s of millions
  - Cost will fall to ~$40 per subscriber
- **WLAN has been adapted for many uses**

Fixed Wireless Access Spectrum

- **Broadband Service Requires**
- **5.8 GHz UNII spectrum:**
  - **Low barrier cost makes market entry**
  - **Issue of interference in more dense**
- **Other potential spectrum allocations**
  - **3.65 to 3.7 GHz: aligns US with international FWA bands**
  - **4.64 to 4.69 GHz – US only**
  - **TDD eliminates additional spectrum pairing requirements for FDD for these bands**

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Monday, December 3, 2001

Part 6: TDD For Mobile Wide Area Services

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Mobile Wide Area Services

- **Requirements for commercial success**
  - differentiated services
  - low cost of service delivery (CapEx/OpEx)
- **TDD technologies provide the basic elements**
  - through spectral efficiency, enabling affordable advanced services
  - through reduced (at least for now) cost of spectrum acquisition
- **Wide range of potential applications/services**
  - consumer: broadband data, voice, … our focus today
  - vertical: meter reading, package tracking, …

Key Application Segments

- **Voice and narrowband (<128 kbps) data systems**
  - offer circuit and packet-switched services
  - employ advanced data+voice handsets and data-only devices

- **Broadband data systems**
  - offer packet-switched IP services and IP backend
  - employ data-only devices (VoIP support)

Voice and Narrowband Data

- **Potential applications in USA**
  - competitive voice service providers
  - local service providers (“community wireless”)
  - data-only providers
- **Ingredients for scaleable success**
  - primarily price differentiation for voice and narrowband data
  - resulting from low infrastructure CapEx/OpEx, ease of deployment
  - inexpensive terminals

Voice and Narrowband Data

- **TDD Technologies**
  - PHS is ideally suited for these applications
  - TDD/TDMA air interface with 300 kHz channel spacing
  - 32 kbps voice, 64 kbps data (128 kbps soon)
  - ISDN network interface
- **Equipment availability**
  - benefits from current worldwide subscribership of 10 M
  - infrastructure equipment available from multiple suppliers
  - wide range of user devices available: voice, voice+data, data
  - PSTN interface is ISDN with mobility enabled CO switch
- **Spectrum requirements**
  - realistic minimum is 5 MHz
  - core band is 1895-1918 MHz per RCR-28 specification

Mobile Broadband Data Services

- **Potential applications in USA**
  - wireless extension of Internet and corporate networks
  - complement to FDD cellular 2/2.5/3G services
- **3G service vision vs. today's 2.5G/3G reality**
  - GPRS pricing for primary internet use roughly $500/mo worldwide
  - not a consumer service, 3G to be priced similarly by most carriers
- **TDD technologies enable affordable mobile broadband**
  - TDD + enabling technologies = superior spectral efficiency
  - superior spectral efficiency minimizes cost of service delivery

Mobile Broadband TDD Technologies

- **UTRA-TDD**
  - TDD/TDMA/CDMA air interface with 5 MHz channel spacing
  - IMT-2000 standard
  - peak per-user data rates in excess of 1 Mbps
- **i-*BURST***
  - TDD/TDMA/SDMA air interface with 625 kHz channel spacing
  - optimized for use with adaptive antennas
  - peak per-user data rates in excess of 1 Mbps
- **Both interface to standard IP network infrastructure**

Broadband Data

- **Equipment availability (UTRA-TDD and i-BURST)**
  - radio equipment available in trial volumes today
  - general availability of radio equipment in 2002
  - IP backend based on widely deployed, standardized IP equipment
- **Spectrum requirements**
  - realistic minimum is 5 MHz
  - targeted mobility bands: PCS, MMDS, IMT2000 1.9 + 2.0 GHz

Summary

- **Solutions for all classes of mobile services**
- **Most efficient use of valuable/limited mobility spectrum**
- **Value proposition enabling**
  - new classes of operators
  - new classes of services
  - new affordable consumer services
- **Relevant near-term Commission actions (among others)**
  - 1910-1930 MHz (3G proceeding)
  - 2010-2025 MHz (3G proceeding)
  - 2500-2690 MHz (evolution of MMDS)

Thank You

http://www.tddcoalition.org