IEEE 802.15.3a

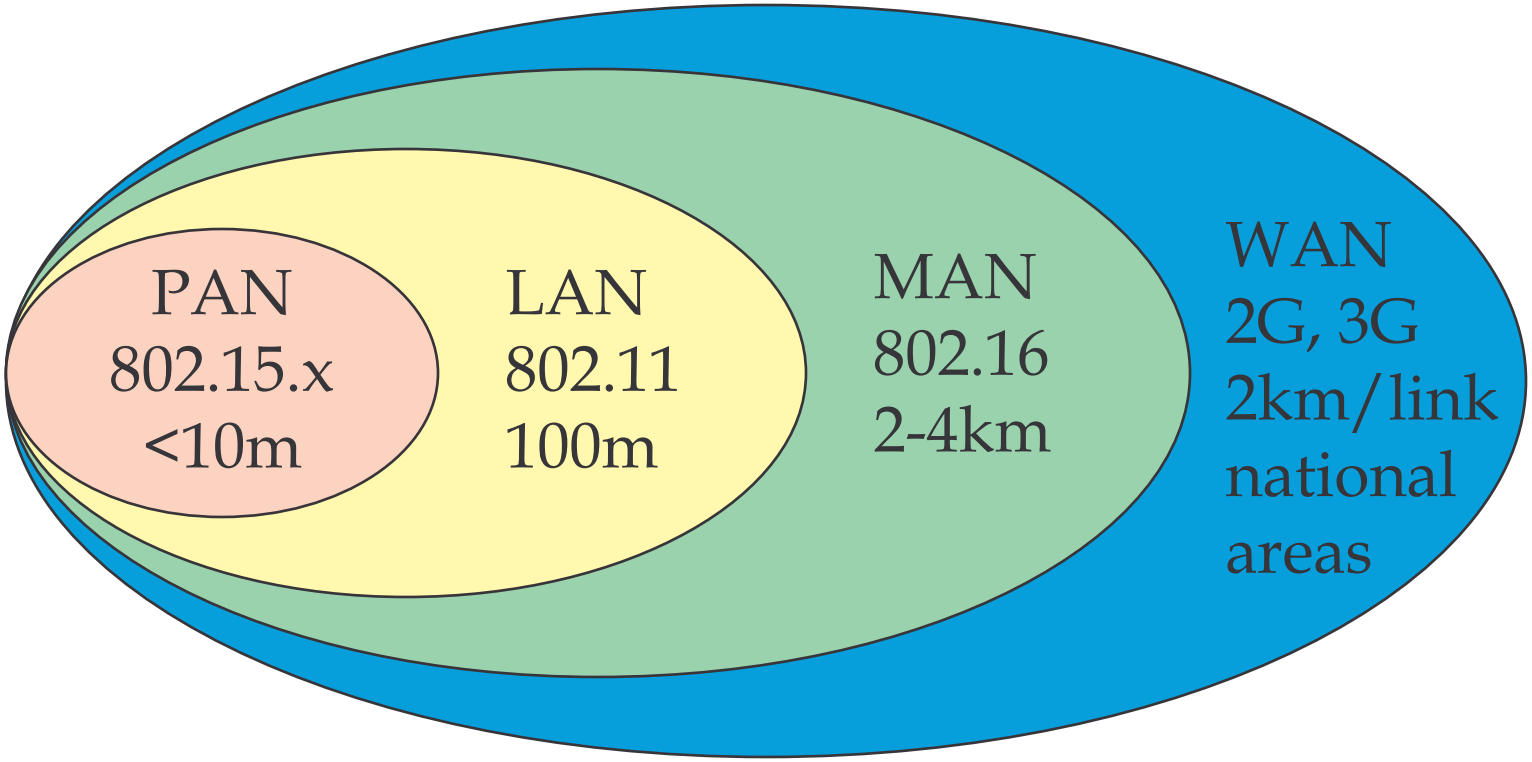
IEEE 802.15.3

- Wireless Data Technology Menagerie
  - WAN, MAN, LAN, PAN
- Ultra Wide Band history
- Current UWB technologies
  - DS-UWB, MB-UWB
- Industry politics:
  - TG3a, UWB Forum, MBOA, WiMedia, WUSB

IEEE 802.15.3a Range of Wireless Data choices

- Wide Area Networks
  - 2G and 3G cellular data systems
- Metropolitan Area Networks
  - 802.16, wireless broadband
- Local Area Networks
  - 802.11/a/b/g/…, wireless LAN
- Personal Area Networks
  - 802.15.1 (Bluetooth™), 802.15.3 & 802.15.4

Network Scales



IEEE 802.15.3a Current Wireless Technologies

Wireless technology	Power mW	Range meters	BW	Rate bps
EDGE 2.5G GSM	600	~2000	200kHz channel	384k
1xEVDO 3G CDMA	600	~2000	1.25MHz/ channel	2.4M
802.16 WiMax	250	~4000	25MHz/ channel	120M
802.11g WiFi	50	100	25MHz/ channel	54M
802.15.1a Bluetooth	1	10	1MHz/ channel	<1M

Bitrate Variation

- All successful wireless technologies have to make adjustments:
  - Noise sources
  - Weather & physical barriers
    - Rain impairs 10-66 GHz WiMax
    - People absorb microwaves
  - Multiple signal paths (self interference)
  - Vulnerable systems (pacemakers, aircraft navigation)
  - Other contending devices:
    - Other mobile phones & towers
    - Other piconets of similar short range technologies
- All MAC layers have overhead
  - e.g. Bluetooth MAC uses 28%

Applications

- Mobile data services provide wide ranging mobile access to email and to the Web, leveraging the mobile network voice infrastructure.
- WiMax: wireless broadband access
  - E.g. bridge to WiFi hot spots, or rural users
- WiFi: faster email & web access on shorter range: e.g. homes, offices, hotspots
- Bluetooth: short range cable replacement

Why replace Bluetooth?

- Get much higher data rates
  - Under optimal conditions, Bluetooth is a 1Mbps signaling technology.
  - Bluetooth is increasing signaling data rates, to 4Mbps.
- Much lower transmit power
  - Bluetooth is 1mW
  - UWB variations are 5-10 times lower

New Applications

- Mobile Internet access for handhelds
  - Comparable or higher speeds than WiFi
    - 802.11n will exceed 100Mbps
  - Lower RF power (100-200 μW vs 50 mW) than WiFi
  - Higher spatial capacity (bps/square meter)
- Fast wireless peripheral access
  - Transfer photos, files, music, video
  - Stream audio and/or video

Spatial Capacity

- This measures the amount of data delivered per user in a given space.
- Example: early mobile phones had a few towers and a lot of power
  - In 1976, NYC could only support 545 users
  - By reducing power, tower spacing is reduced
  - Denser tower spacing covers more users
- High capacity = more users, better served

Note: the following table is not corrected for MAC overhead

Comparisions

Type	Range m	area m^2	data rate	capacity $kbps/m^2$
802.15.1	10	314	1M	3.2
802.11b	100	31416	11M	0.35
802.11g	100	31416	54M	1.72
802.11a	50	7854	54M	6.88
802.15.3	10	314	55M	175

RF Power per bit

- This measures the energy (joules) it takes to deliver a fixed amount of data.
- Approximate calculation is simple:
  - Time to send data (data/rate) x Transmit power
- These are lower bounds, due to MAC overhead and MAC/PHY chip power
  - e.g. Bluetooth MAC will eat at least 28%
  - chip power may easily exceed RF power
- To get rid of leading zeros, calculate joules/MB rather than joules/bit.

RF Power per MB

Type	Bit rate	TX Power	mJ/MB
802.11b	11Mb	50mW	36.4
802.11a	54Mb	200mW	29.6
802.11g	54Mb	50mW	7.4
802.15.1	1Mb	1mW	8.0
802.15.3	55Mb	200uW	0.03

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Ultra Wide Band

- Very low power: 200μW
- Very wide bandwidth: 3.1-10.6 GHz
- First designs: strings of pulses
- First standard: 802.15.3-2002
- New proposals in 802.15.3a:
  - Xtreme Spectrum DS-CDMA
  - MultiBand OFDM
  - DS-UWB Merge Proposal #2

IEEE 802.15.3a

UWB Characteristics

- High Rate WPAN:
  - Short Range (at least 10m, up to 70m possible)
  - High Data rates (currently up to 55 Mb/s, to be increased by TG3a to 100-800 Mb/s)
- Dynamic Topology:
  - Mobile devices often join and leave piconet
  - Short time to connect (<1s)
- Ad-hoc network with Multimedia QoS provisions
  - TDMA for streams with time based allocations
  - Peer to peer connectivity
- Multiple Power Management Modes:
  - Designed to support low power portable devices

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UWB Characteristics

- Low price point, low complexity and small form factor (e.g., Compact Flash)
- Secure Network:Authentication using higher layer protocol (PK or other)
  - Dynamic key distribution
  - Shared Key encryption (AES 128) and integrity (data and commands) - CCM
- Ease-of-use:
  - Dynamic coordinator selection and handover
  - Does not rely on a backbone network
- Designed for relatively benign multipath environment:
- – Personal or home space (RMS delay spread <25ns)

UWB Applications

- Video and audio distribution:
  - High speed DV transfer from a digital camcorder to a TV screen
  - HD MPEG2 (or better) between video players/gateways and multiple HD displays
  - Home theater audio distribution
  - PC to LCD projector
  - Interactive video gaming
- High speed data transfer:
  - MP3 players
  - Personal home storage
  - Printers & scanners
  - Digital still cameras to/from kiosk

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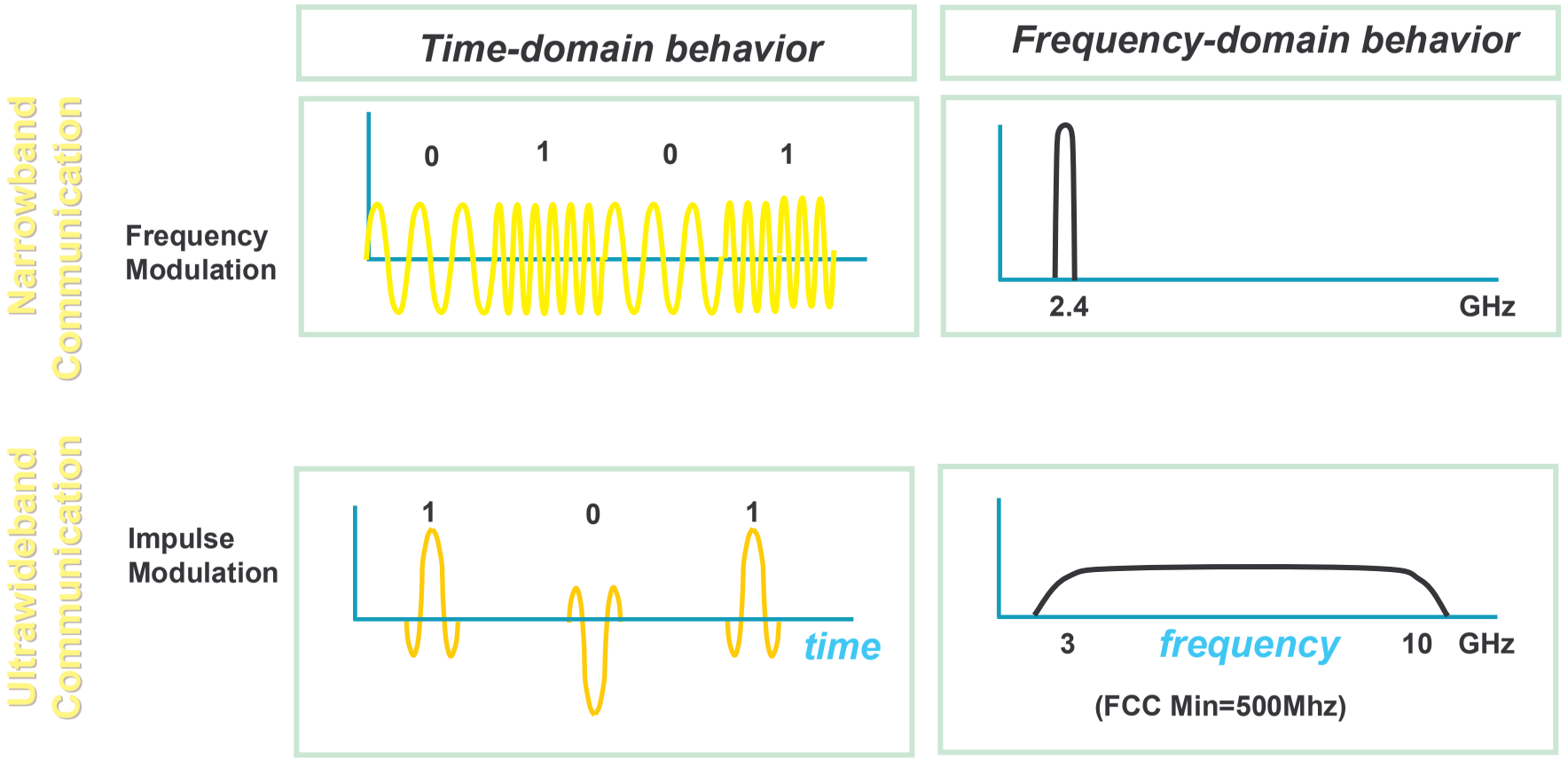
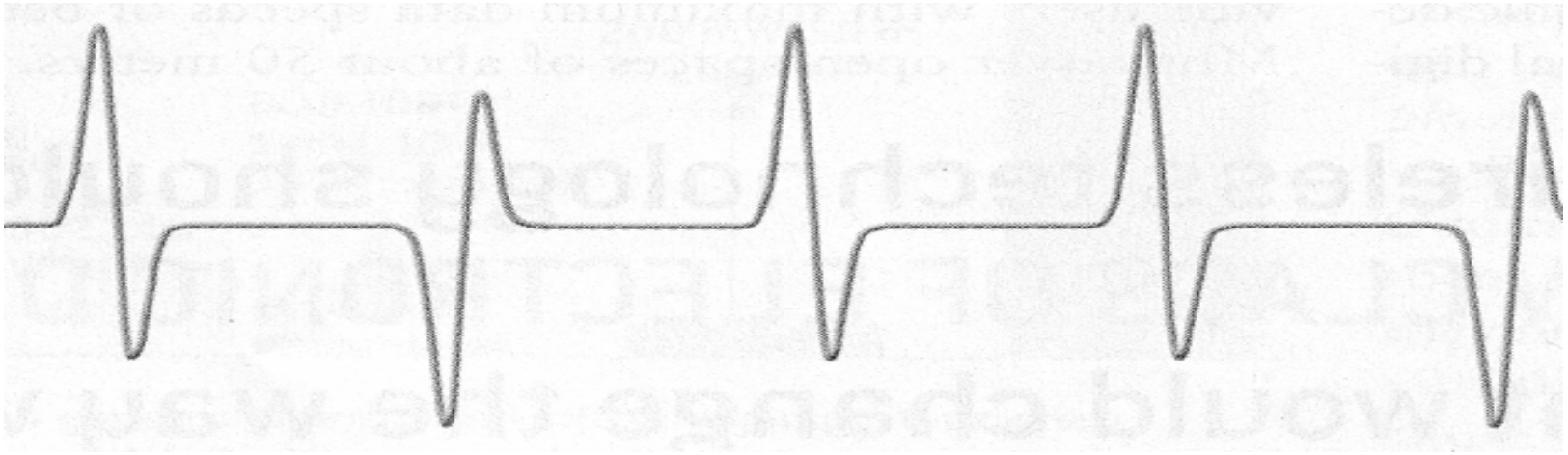
What is UWB?



- Communication that occupies more than 500 MHz of spectrum
- Communication with fractional bandwidth of more than 0.2
- More possibilities than pulses

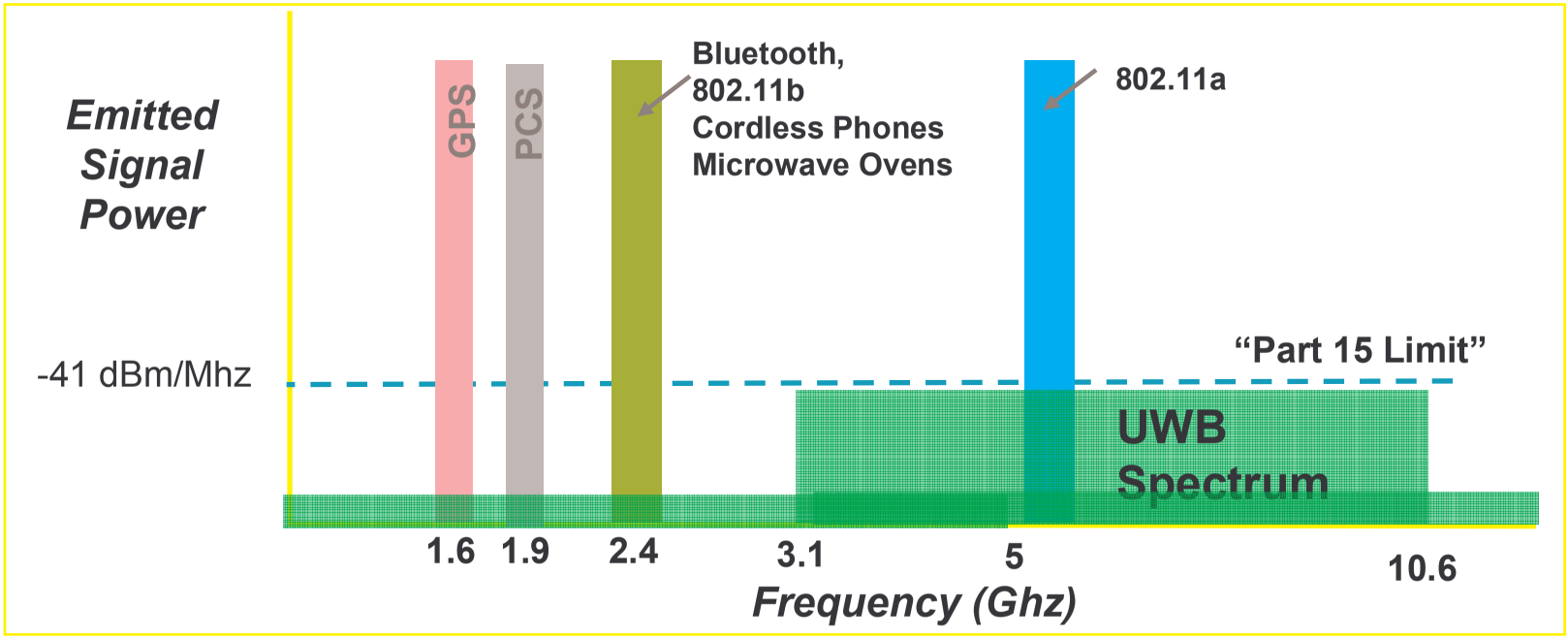
First UWB Designs

- Used similar wide bandwidth and low power
- Used wavelet pulses (see below)
- Data modulated by amplitude and pulse-to-pulse period
- Many technical and regulatory issues



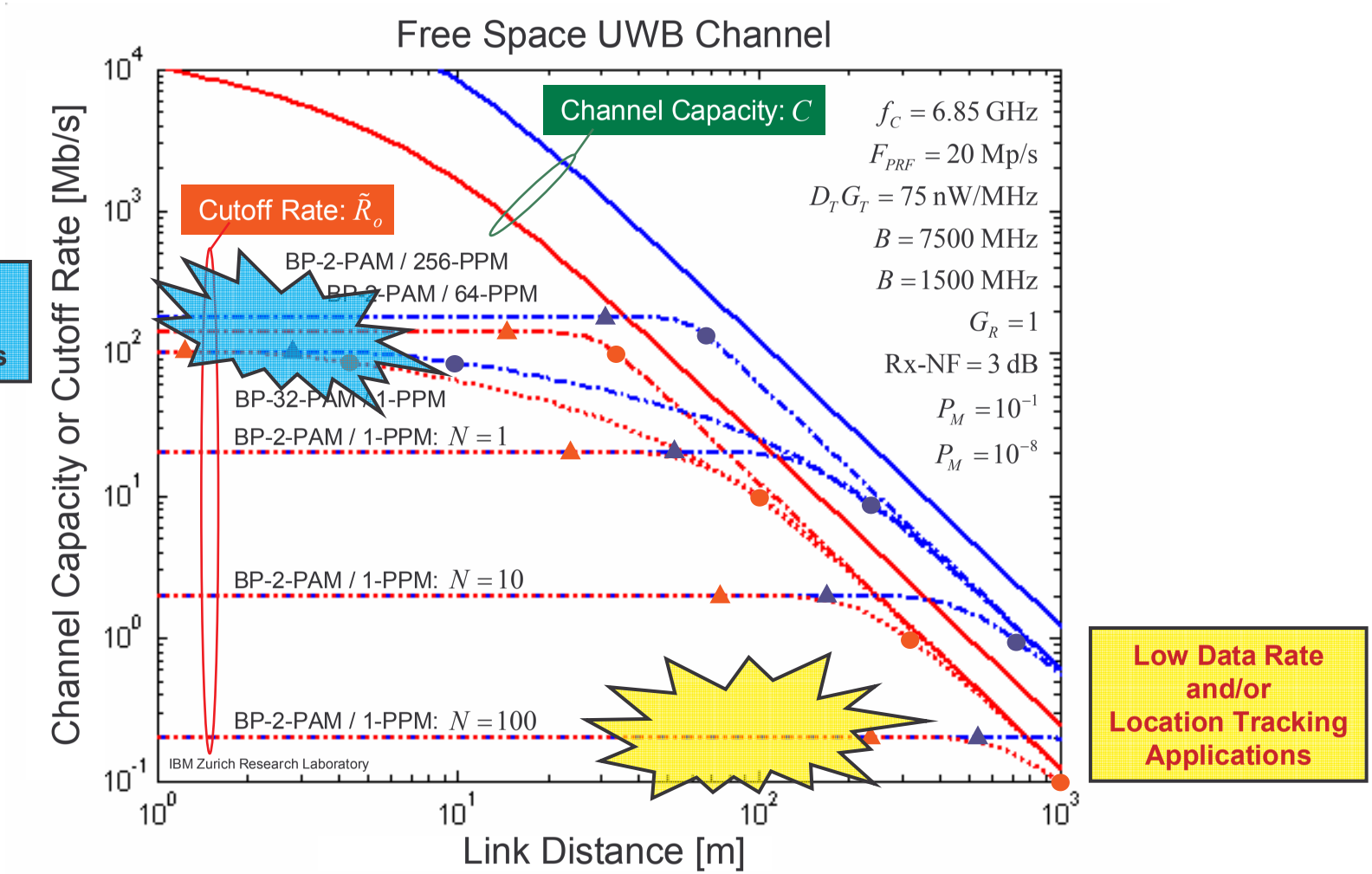
UWB Spectrum

- FCC ruling permits UWB spectrum overlay



- FCC ruling issued 2/14/2002 after ~4 years of study & public debate
- FCC believes current ruling is conservative
- Worldwide regulations differ – Japan, EU, Asia…

Theoretical Limits and Application Space



Very High Data Rate Applications

Low Data Rate and/or Location Tracking Applications

IEEE 802.15.3a Why is UWB so interesting?

- 7.5 Ghz of "free spectrum" in the U.S.
  - FCC recently legalized UWB for commercial use
  - Spectrum allocation overlays existing users, but its allowed power level is very low to minimize interference
- Very high data rates possible
  - 500 Mbps can be achieved at distances of 10 feet under current regulations
- Simple CMOS transmitters at very low power
  - Suitable for battery-operated devices
  - Low power is CMOS friendly
  - "Moore's Law Radio" --Data rate scales with the shorter pulse widths made possible with ever faster CMOS circuits
- Low cost
  - Nearly "all digital" radio ?
  - Integration of more components on a chip (antennas?)

Advantages

- Range/bitrate scalability
  - Extremely good W/Mbit communication
- Localization
  - Sub-centimeter resolution using pulse leading edge detection
  - passes through building blocks, walls, etc. (LOS not required)
- Robustness to interference and multipath
  - Path delay >> pulse width => possible to resolve different signal paths
  - Use a RAKE receiver to turn multipath into a consistent advantage
  - Consistent range

Advantages

- Radio as a sensor (radar)
  - Localization and multipath robustness are a consequence of this
  - Channel characterization reveals absorptive/reflective sources and their positions
- Difficult to intercept in traditional ways
  - Low interference (that's why we allow it, after all)
  - Very low spectral energy density
- Size
  - 4.5 mm^2 in 90 nm process for high data rate designs
  - integration of more components onto a single chip

IEEE802.15.3 (2002) First Standard

- All 802 family standards focus on
  - PHY layer (e.g. signals, carriers)
  - MAC (media access control) layer
  - See model on next slide
- Original scope was at least 20Mbps, but with similar range and power to Bluetooth, using 2.4 GHz ISM band
- Subsequent work, e.g. 802.15.3a, and MBOA, build on this standard

IEEE 802.15.3a MultiBand OFDM Alliance

"To develop the best overall solution for ultrawideband- based products in compliance with worldwide regulatory requirements, to ensure peaceful coexistence with current and future spectrum users, and to provide the most benefits to the broadest number of end consumers."

http://www.multibandofdm.org

Now unite[illegible]Media Alliance

IEEE 802.15.3a

UWB Layer Model

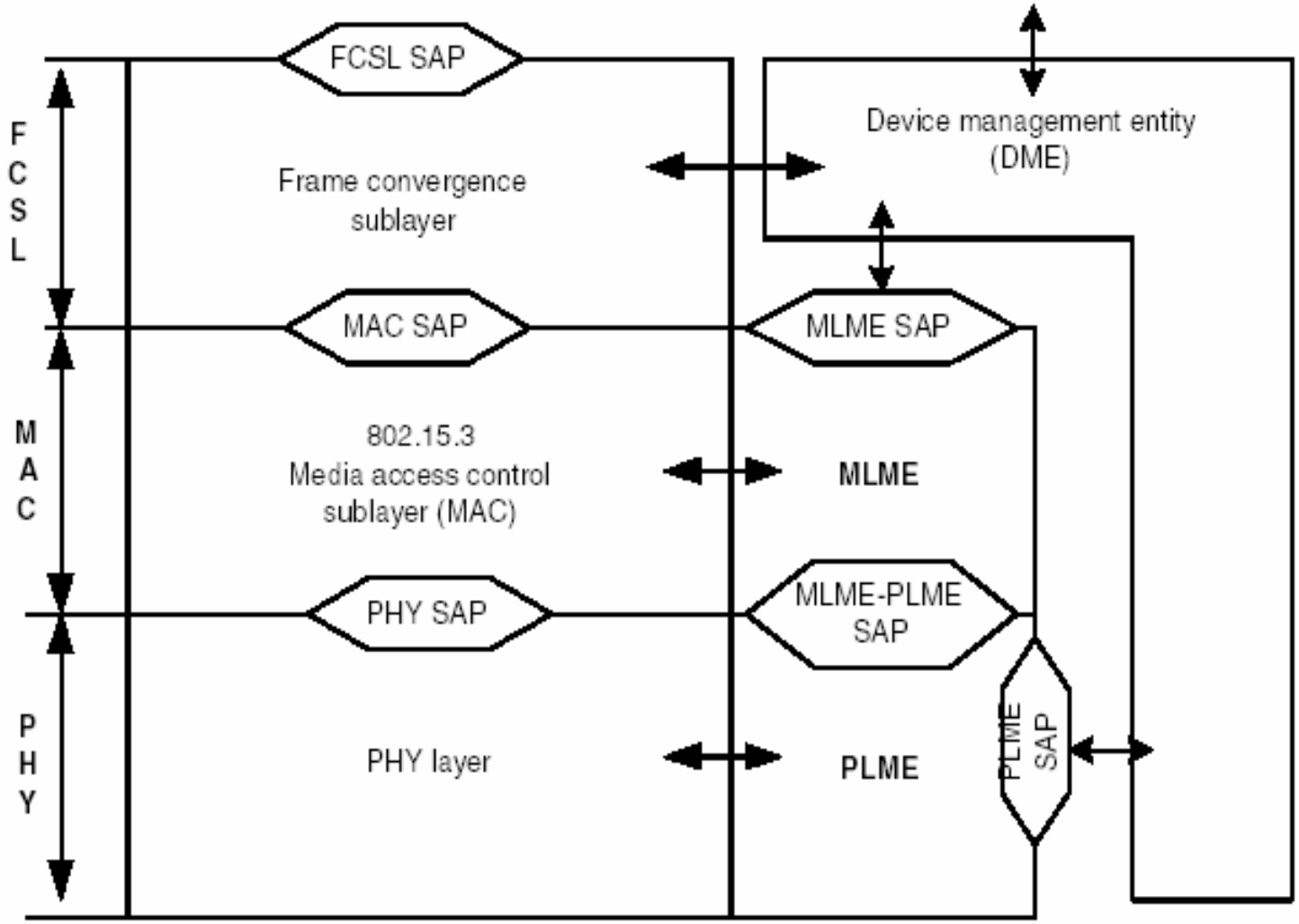


Figure 3—The reference model used in this standard

IEEE802.15.3 PHY

- 2.4GHz ISM band (2.4000-2.4835 GHz)
  - Shared with Bluetooth and 802.11/b/g
- Split into 5 bands
  - 3 bands used to avoid collision with 802.11
  - 15 MHz per channel
- Symbol timing is similar to 802.11b
  - 11 Mbaud symbol rate
  - Data rates of 11, 22, 33, 44 and 55 Mbps

IEEE 802.15.3 Coexistence Support

- Passive scanning
- Dynamic channel selection
- Channel quality requests
- Link quality and RSSI
- Channel plan for minimal overlap
- Lower transmit power than Wi-Fi or 15.1
- Transmit power control
- Neighbour piconet capability

802.15.3 MAC

Goals:

- Fast Connect Time
- Ad Hoc Networks
- Dynamic Membership
- Efficient Data Transfer
- Data transport Quality-of-Service (QoS)
- Security, including:
  - Data encryption
  - Data integrity
  - Command integrity

802.15.3 MAC functions

- The PicoNet Controller (PNC) manages piconets = ad hoc associations (next slide)
- Controls PicoNet security
- Allocates PicoNet data transfer capacity by allocating piconet time
- Manages traffic in SuperFrames
- Manages service discovery and configuration
- Manages PicoNet range via beacon power

802.15.3 Piconets

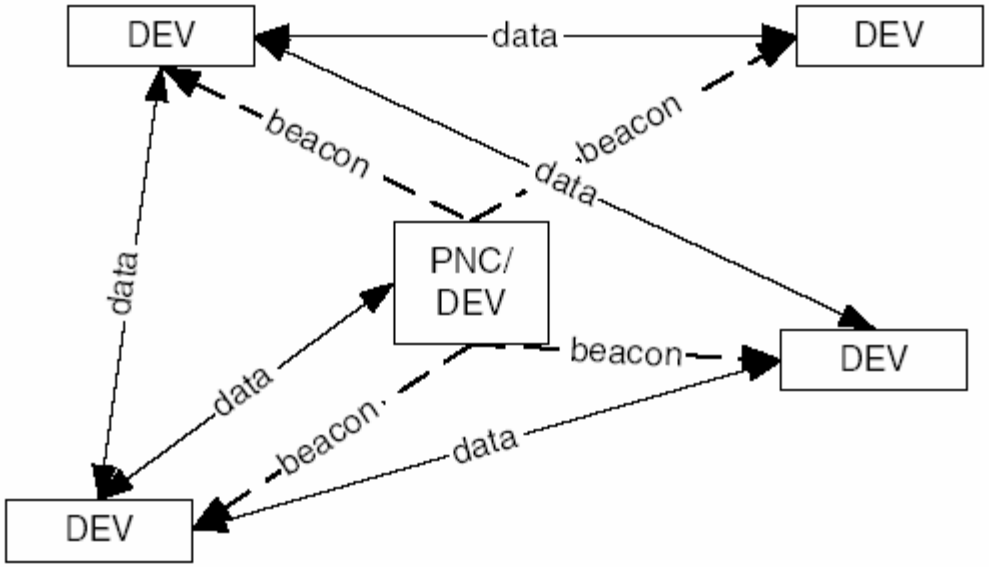
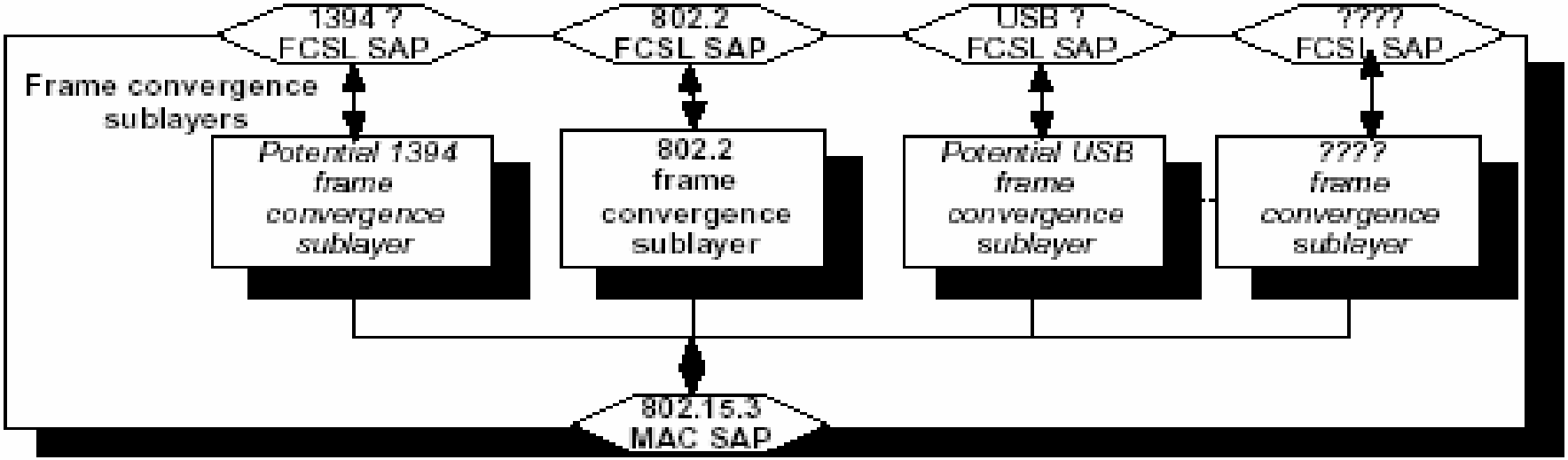


Figure 1—802.15.3 piconet elements

Frame Convergence Sublayer



Original DS-CDMA

- Original design from:
  - ParthusCeva & Xtreme Spectrum
  - Communications Research Lab (now NiCT)
  - OKI Semiconductor
- Now driven by UWB Forum
  - led by Motorola/Freescale & NiCT
- Two bands, bracketing NII (5GHz) band
  - 3 modes: lower, upper, both
  - Each symbol is a series of wavelet pulses
- Data rates derived by different length spreading codes: 1 – 24 pulses

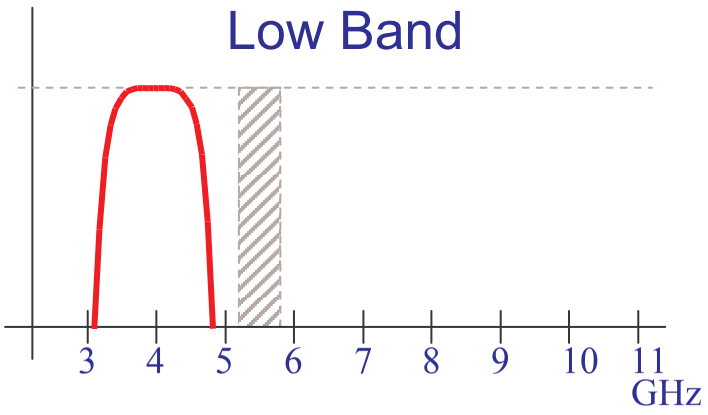
Current DS-UWB

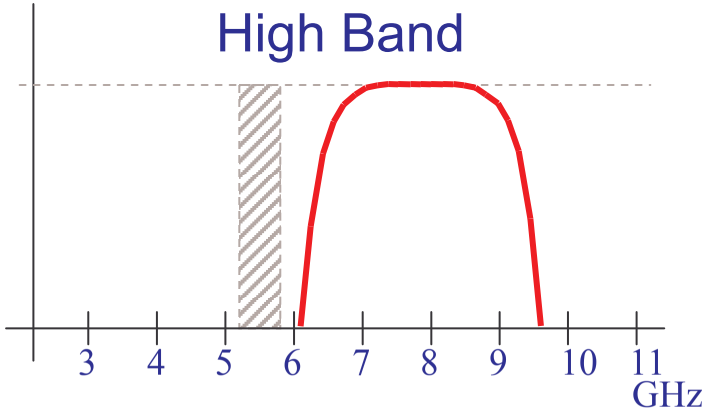
- Motorola & NiCT (formerly CRL) did a major redesign: "Merged Proposal #2"
- MBOK demodulation is removed
- New: Adjustments for data rate vs distance (measured by signal strength)
- New: Common Signaling Mode
  - to allow one device to negotiate between a DS-UWB PHY and a MB-UWB PHY
  - spectrum adjustments so they can co-exist

DS-UWB modulation

- Two bands:
  - 1.75 GHz = 3.1 to 4.85 GHz
  - 3.5 GHz = 6.2 to 9.7 GHz
  - In higher band, double chip rate and power
- BiPhase pulse modulation
  - Root-shaped raised cosine pulses
- Each symbol is a series of pulses
- Data rates derived by different length spreading codes: 1 – 24 pulses

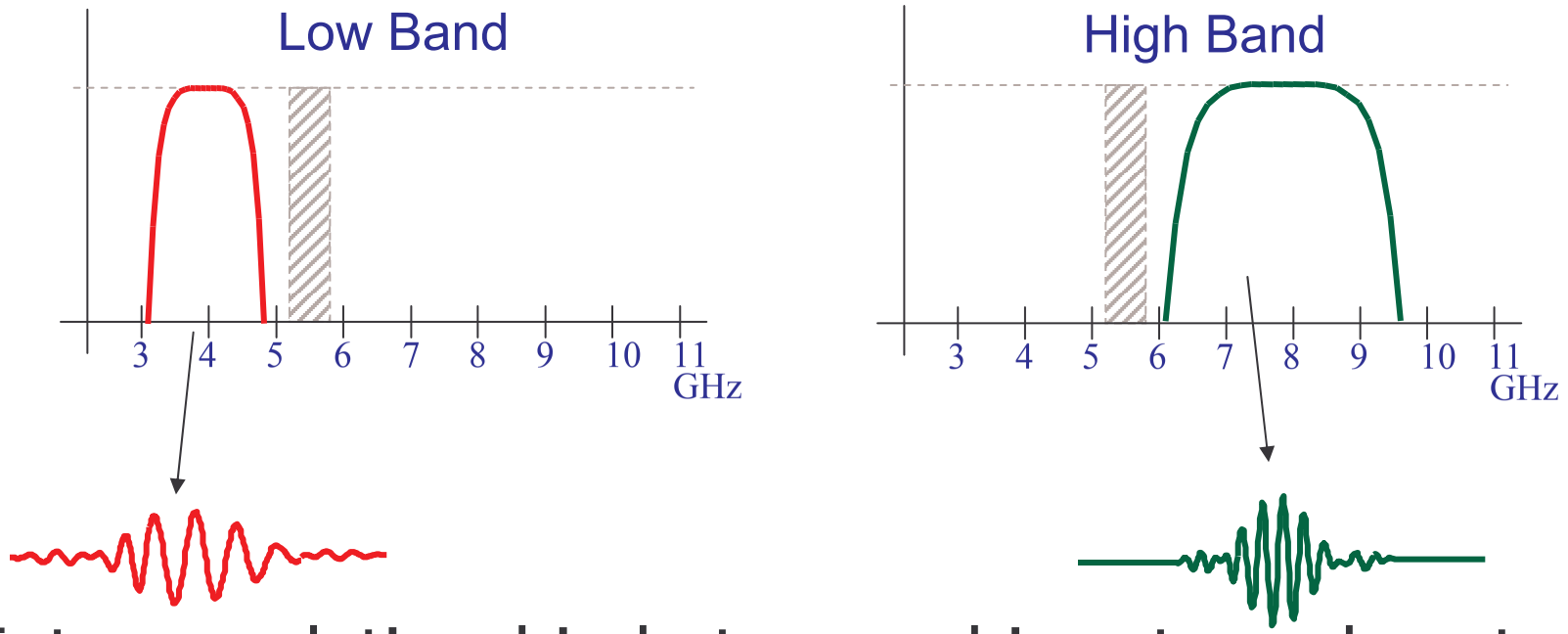
DS-UWB Bands





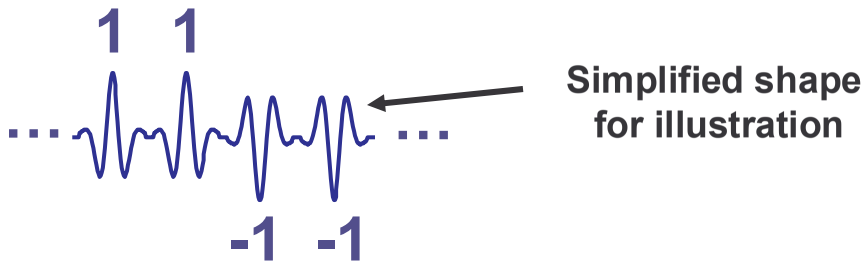
- Each piconet operates in one of two bands
  - Low band (below U-NII, 3.1 to 4.9 GHz) – Required
  - High band (optional, above U-NII, 6.2 to 9.7 GHz) – Optional
- Different "personalities": propagation & bandwidth
- Both have ~ 50% fractional bandwidth

DS-UWB Pulses

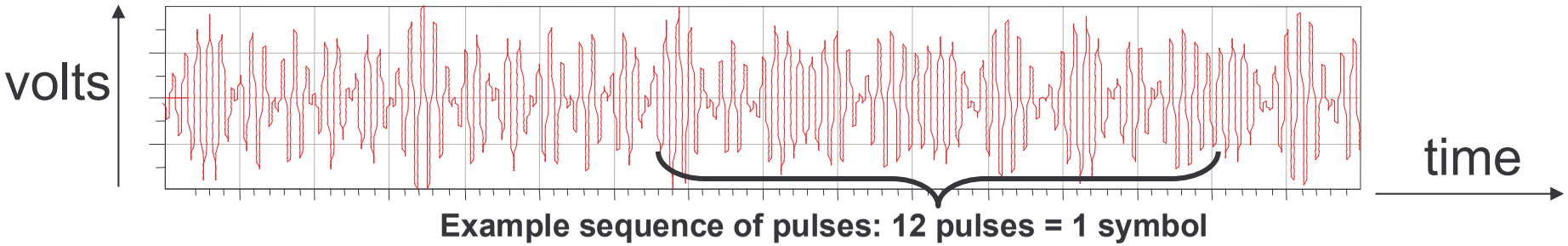


- Integer relationship between chip rate and center frequency
  - Center frequency is always 3x the chip rate
  - Results in a pulse shape that always has the same phase relationship between carrier and pulse

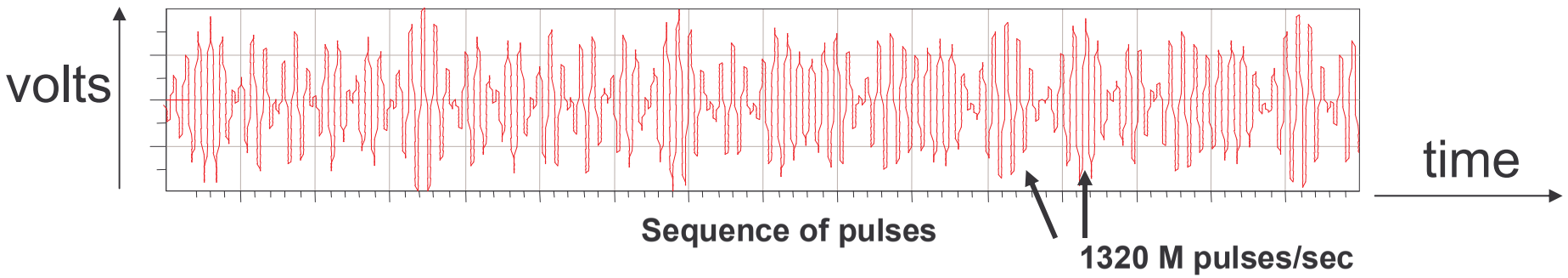
DS-UWB Spreading Codes



- Pulses are transmitted in sequences
  - "Ternary" sequences – elements are +/-1 or 0
- A sequence of pulses delivers each bit
  - Different sequence lengths = different bit or "symbol" lengths
  - Sequences range from length 24 pulses to pulse



Achieving Different Data Rates



- Pulses or "gaps" are sent at a fixed chip rate
  - "Nominal" chip rate is 1320 MHz
  - Actual chip rates slightly offset for different piconets
- Data modes use different codes, same chip rate
  - Example: 1320 MHz/24 chips = 55 M symbols/sec

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Data Rates vs Range

Data Rate	FEC Rate	Code Length	Symbol Rate	Range (AWGN)
28 Mbps	½	24	55 MHz	29 m
55 Mbps	½	12	110 MHz	22 m
110 Mbps	½	6	220 MHz	18 m
220 Mbps	½	3	440 MHz	13 m
500 Mbps	¾	2	660 MHz	7 m
660 Mbps	1	2	660 MHz	3 m
1000 Mbps	¾	1	1320 MHz	5 m
1320 Mbps	1	1	1320 MHz	2 m

Similar Modes defined for high band

802.15.3a: Multi-Band OFDM

- Original proposal by TI
- 15 other contributing companies
- Divides 3.1–10.6 GHz band into bands
  - 528 MHz each
- Modulation is Orthogonal Frequency Division Multiplex (OFDM)
  - Also used for 802.11a/g/n, 802.16a (WiMax), DSL, 802.20, 4G cellular

802.15.3a

- 802.15.3 has created a Task Group to create an alternate PHY standard to address very high data rate applications
  - Goal of > 110Mbps @ 10 m, > 400 Mbps @ 5 m
  - 1394a, USB2.0 HS cable replacement
  - DV50, DV100, HD DVD, High resolution printer and scanner, fast download speed for MP3 players, digital still cameras

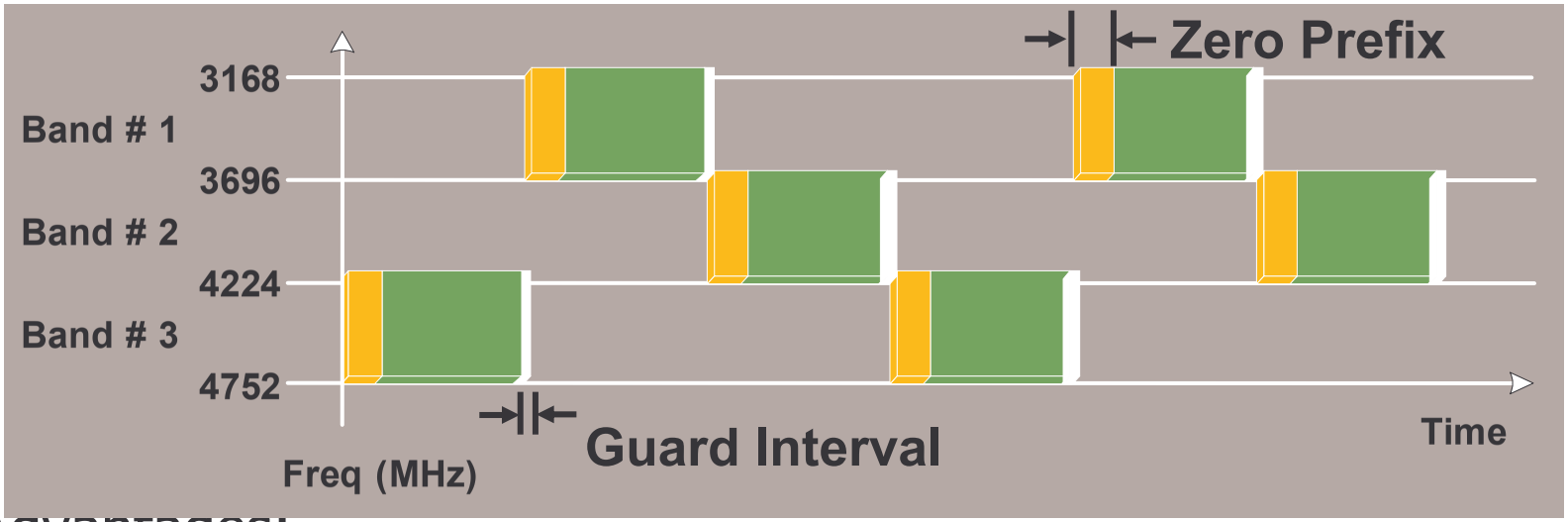
MB-UWB Modulation

- Divide spectrum into 528 MHz bands

- Advantages:
  - Transmitter and receiver process smaller baseband bandwidth signals (528 MHz).

MB-UWB Modulation

- Also:
  - Band Interleaving, Zero Prefixes, & Guard Intervals



- Advantages:
  - Frequency diversity, full allowable Transmit power
  - Robustness to Multipath propagation effects
  - Transmit/Receive settling times
  - Facilitates future "Cognitive Radio"

Does OFDM Work?

- 128-point IFFT/FFT generates and recovers OFDM carriers
- Constellations limited to QPSK
- Facilitates future “Cognitive Radio”

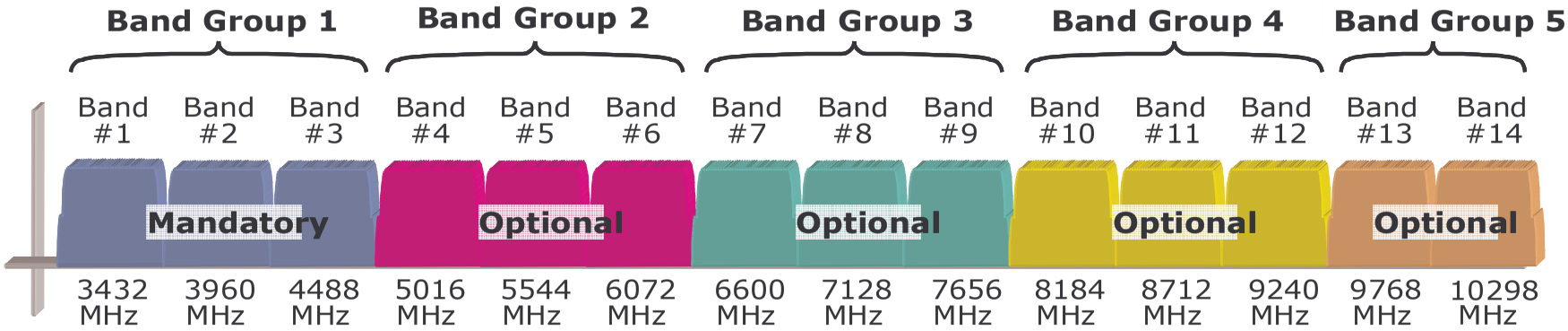
IEEE 802.15.3a Aside: Cognitive Radio (5G)

"A cognitive radio (CR) has a computation model of itself. It knows that it is a smart radio, and it has a user who does certain things. If you're a journalist, you might be willing to pay a premium to get higher speech quality. If a CR detected an interview, and it would cost three cents a minute for a clearer signal, [a message] would pop up on the display asking if you want to pay three cents more a minute for clearer audio. Over time, it would learn and would build into the computation model that the user likes high-quality speech when doing interviews. This computation model of itself, of the user and the network, plus the machine learning means that the user doesn't have to reprogram it and keep telling it what to do. ... There isn't a true working model yet. It may be five to 10 years out."

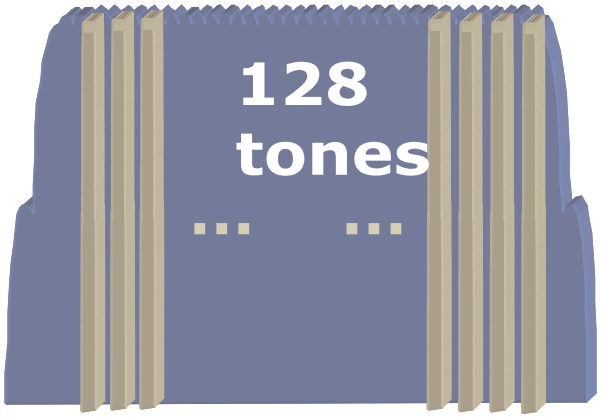
Joseph Mitola, (works with DARPA and NSA)

IEEE 802.15.3a

MB-UWB PHY Spectra



Link Margin Ref. (0 dB). -02.7 dB **-04.9 dB** **-06.5 dB**



Channel Number	Band Group 1 Length 6 TFC					
1	1	2	3	1	2	3
2	1	3	2	1	3	2
3	1	1	2	2	3	3
4	1	1	3	3	2	2

MBOA PHY Specification 1.0
- Band Switching
  - Within Band Set #1
  - 3.168 – 4.752 GHz
- Bands 1, 2 and 3
  - Each occupy 528 MHz
- Band Subcarriers
  - 128 tone OFDM
  - Tone width: 4.125 MHz
  - Tone modulation: QPSK

Global Solution: Flexible band plan and use of OFDM subcarriers allows for "spectrum shaping" which can be used to meet worldwide regulatory requirements

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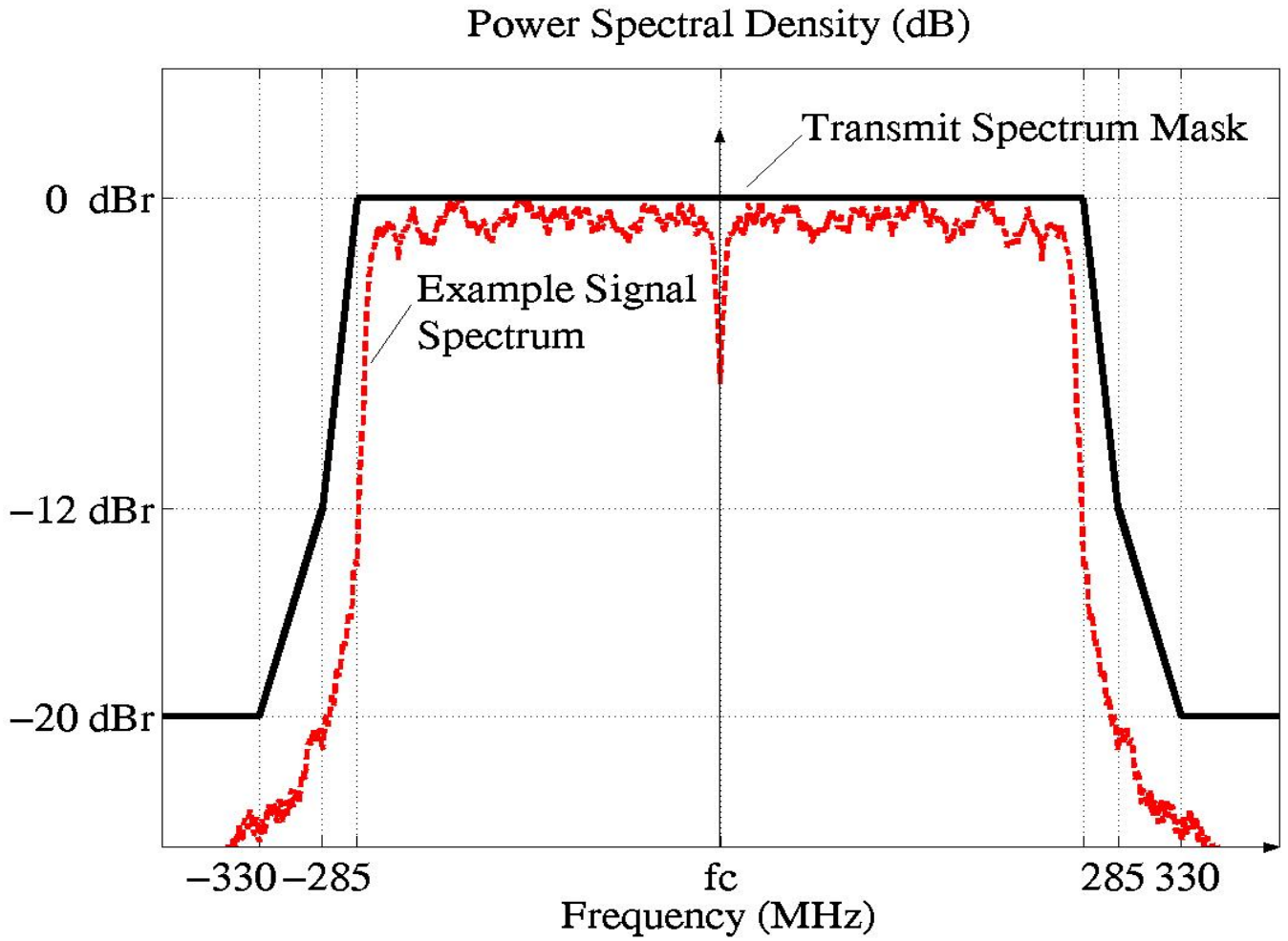
MB-UWB Spectra Detail



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MB-UWB System Parameters

- System parameters for mandatory and optional data rates:

Info. Data Rate	55 Mbps*	80 Mbps**	110 Mbps*	160 Mbps**	200 Mbps*	320 Mbps**	480 Mbps**
Modulation/Constellation	OFDM/QPSK	OFDM/QPSK	OFDM/QPSK	OFDM/QPSK	OFDM/QPSK	OFDM/QPSK	OFDM/QPSK
FFT Size	128	128	128	128	128	128	128
Coding Rate (K=7)	R = 11/32	R = 1/2	R = 11/32	R = 1/2	R = 5/8	R = 1/2	R = 3/4
Spreading Rate	4	4	2	2	2	1	1
Data Tones	100	100	100	100	100	100	100
Info. Length	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns	242.4 ns
Cyclic Prefix	60.6 ns	60.6 ns	60.6 ns	60.6 ns	60.6 ns	60.6 ns	60.6 ns
Guard Interval	9.5 ns	9.5 ns	9.5 ns	9.5 ns	9.5 ns	9.5 ns	9.5 ns
Symbol Length	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns	312.5 ns
Channel Bit Rate	640 Mbps	640 Mbps	640 Mbps	640 Mbps	640 Mbps	640 Mbps	640 Mbps
Multi-path Tolerance	60.6 ns	60.6 ns	60.6 ns	60.6 ns	60.6 ns	60.6 ns	60.6 ns

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802.15.3 UWB Range vs Rate

UWB type	Power μW	Range meters	BW MHz	Rate Mbps
802.15.3	200	10	15	55
MB-UWB	100	10	528	480
DS-UWB	100	13	1750/3500	220
DS-UWB	100	7	"	500
DS-UWB	100	2	"	1320

MAC changes: TG3b & MBOA

- IEEE 802.15 TG3b is working on an improved MAC, in parallel with TG3a.
  - add security & streaming to 802.15.3 MAC
- MBOA is developing a new MAC
  - True peer-to-peer; PNC not needed
  - Supports multiple simultaneous protocols
  - Tuned to the needs of WUSB and W1394
  - Isochronous (i.e. time-sensitive) media streaming support

IEEE 802.15 TG3a Politics

- The deadlock has lasted since July 2003
  - Some deadlocks break (e.g. 802.11g)
- The MB-UWB faction had 54% of the vote in September 2004, far from the 75% needed.
  - DS-UWB had a one vote margin in July 2004.
- MB-UWB has more market support so far
  - 16 companies claim to be developing chips
  - That is not translating into committee votes
  - A lot of voters have given up; they are back at the office racing to get products ready to ship!!

Prognosis & Predictions

- 802.15 WG3a looks fatally deadlocked.
- Both MB-UWB and DS-UWB could become distinct 802.15 standards (e.g. '15.6', '15.7').
  - Like 802.3 (Ethernet) and 802.5 (Token Ring)
  - The antagonists would need mutual tolerance
- MB-UWB will likely win in two markets:
  - Wireless multi-media/entertainment (e.g. W-1394)
  - Wireless peripheral connectivity (e.g. W-USB)
- DS-UWB will likely have a niche in PDAs, given Freescale's presence there.
  - NiCT may help generate critical mass in Japan