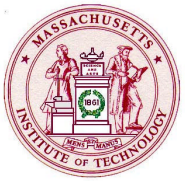
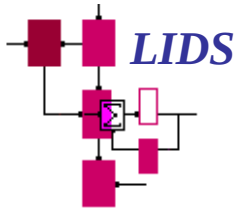




Ultra-Wide Bandwidth: An Extreme Wireless Technique ?

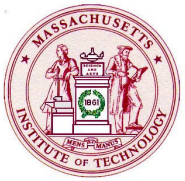
Moe Win

Laboratory for Information & Decision Systems (LIDS)

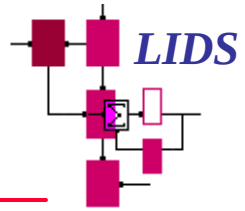
Massachusetts Institute of Technology

Cambridge, MA 02139 USA

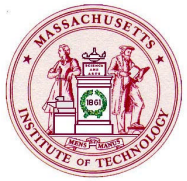
moewin@mit.edu



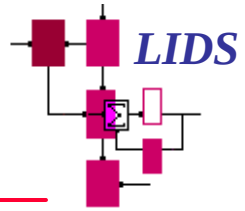
Outline



- UWB signals
- Some Historical Perspectives
- FCC Regulations
- Possible Usages
- Standardization
- Sample Research Activities
- Conclusions



Typical UWB Signals



"UWB radio systems typically employ pulse modulation where extremely narrow (short) bursts of RF energy are modulated and emitted to convey information. … the emission bandwidths … often exceed one gigahertz. In some cases, "impulse" transmitters are employed where the pulses do not modulate a carrier. Instead, … the resonant frequency of the antenna determines the center frequency … characteristics of the antenna … further affecting the shape of the radiated signal."

Federal Communications Commission
ET Docket 98-153, First Report and Order
Adopted: February 14, 2002, Released: April 22, 2002

`http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf`

Usage

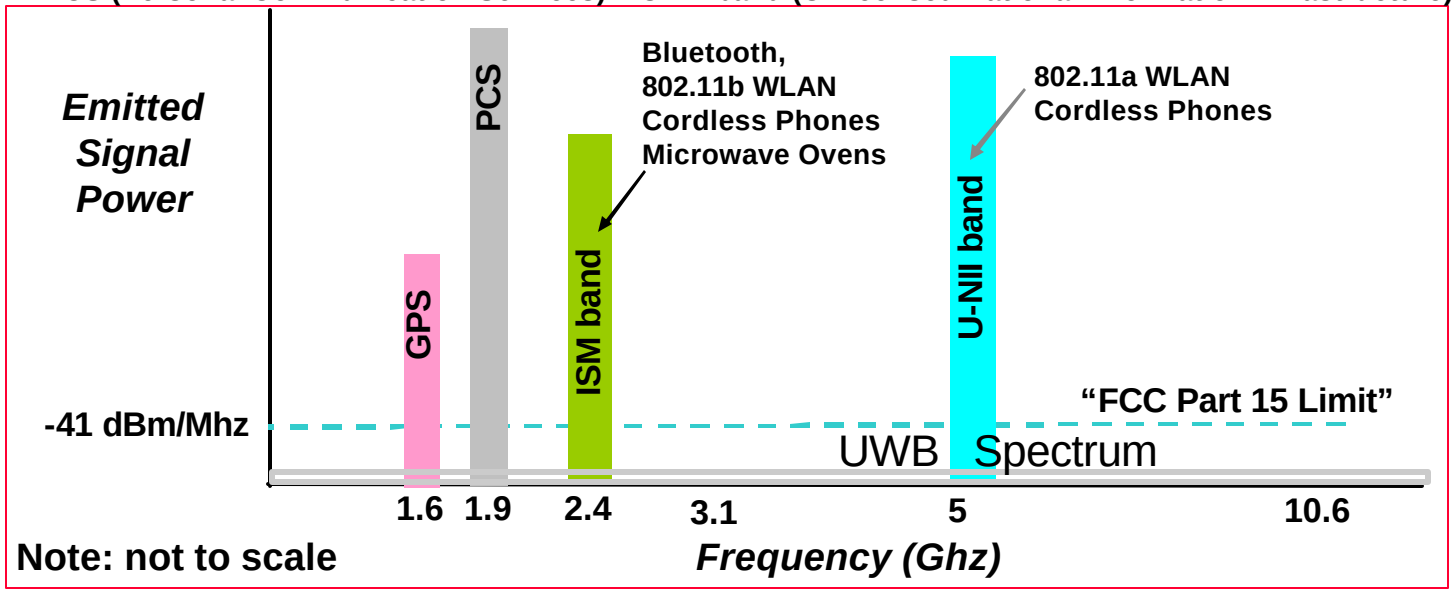
"UWB devices can be used for precise measurement of distances or locations and for obtaining the images of objects buried under ground or behind surfaces. UWB devices can also be used for wireless communications, particularly for short-range high-speed data transmissions suitable for broadband access to networks."

Federal Communications Commission
ET Docket 98-153, First Report and Order
Adopted: February 14, 2002, Released: April 22, 2002

`http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf`

UWB spectrum

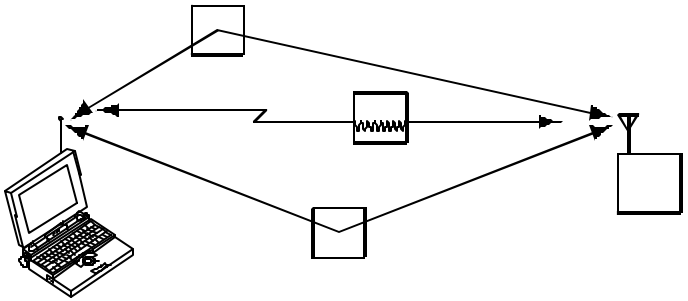
- GPS (Global Positioning System)
- PCS (Personal Communication Services)
- ISM band (Industry Scientific Medical)
- U-NII band (Unlicensed National Information Infrastructure)



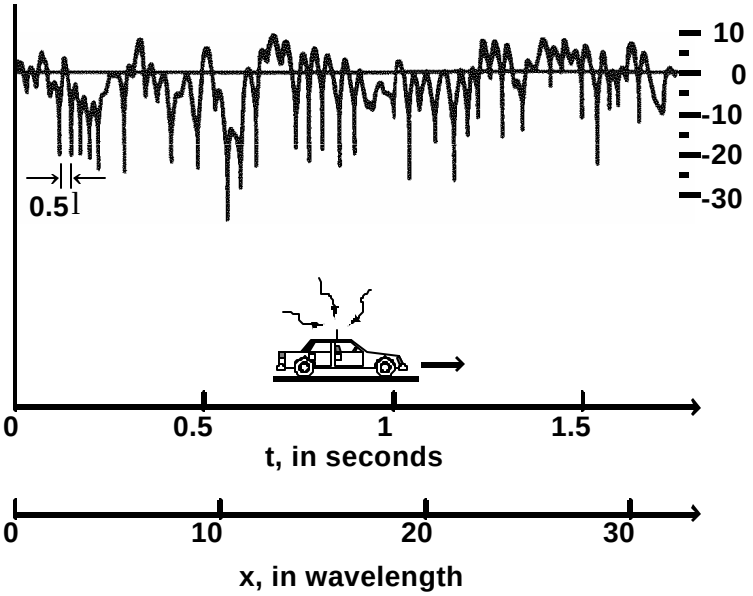
- UWB is presently legal only in the US
  - Regulatory activities underway in Europe, Japan, and China
- FCC ruling permits UWB spectrum overlay
- Uses same spectrum as existing services
  - Information spread over extremely wide spectrum; low power spectral density
  - Small interference – looks like noise to other systems

Motivation

- **Multipath Fading:**
  - X Major Limitation for Conventional Wireless Transmissions in Multipath Channels
  - X Large Fading Margin

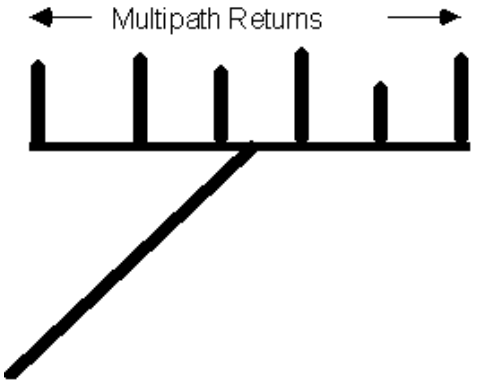


Constructive and Destructive Interference of Arriving Rays



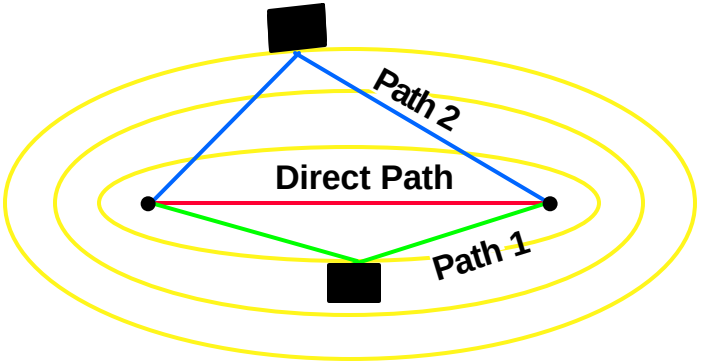
Motivation

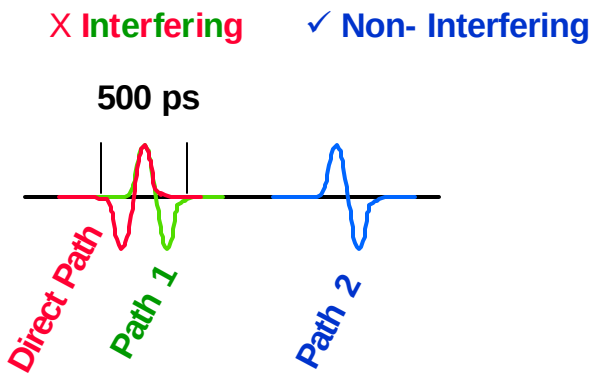
- Wideband Systems:
  - ✓ Alleged Disadvantage ➡ Advantage
  - ✓ Ability to Resolve Multipath Components
  - ✓ High Degree of Path Diversity Inherent in the Channel
  - ✓ Diversity Reception by Rake-Like Architecture



“Turn Lemon into Lemonade”

Multipath Advantage

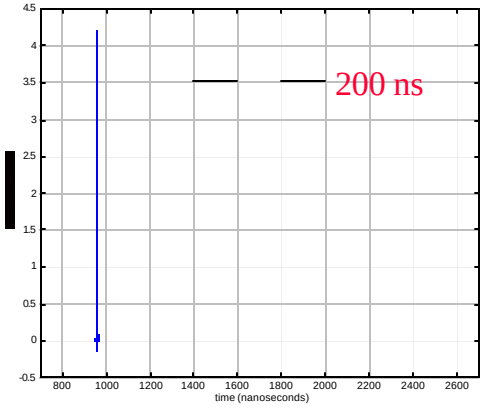




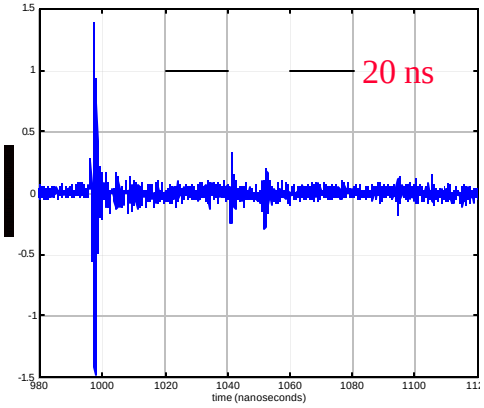
- **Wide Bandwidth gives Resolvable multipath**
  - ✓ Reduce Fading Even in Dense High Multipath Channels (i.e. Indoor Environment, Factories, Warehouse, Office)
  - ✓ Small Fading Margin
  - ✓ Reduce XMTR Power
  - ✓ High Degree of Path Diversity by Rake Reception

Representative Measurements

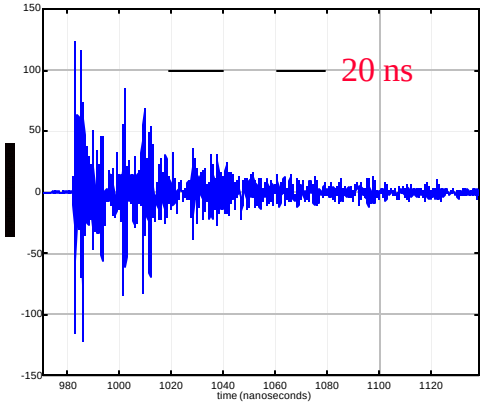
Transmitted Signal

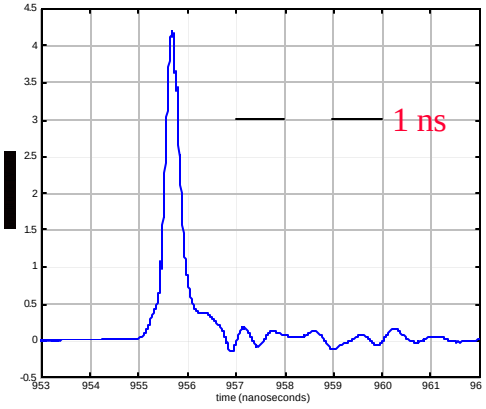


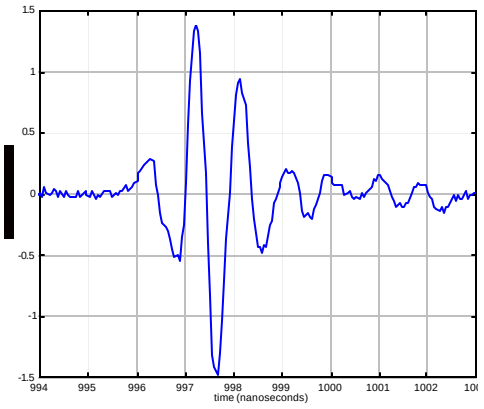
Outdoor Rcvd Clear LoS

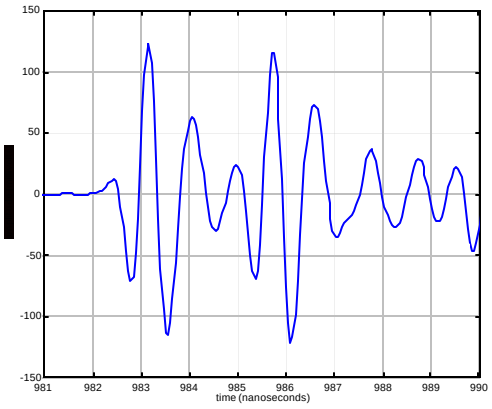


Office Rcvd Clear LoS



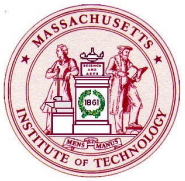




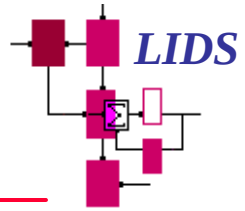


Historical Perspective

- 1901: Marconi's Spark Gap Transmission
- ca. 1960: Ross, et al., develop transient analysis of microwave networks at Sperry Research
- ca. 1968: Harmuth explores non-sinusoidal signals
- 1971: Ross files pat. for impulse Xmit/Rcv technology
- 1971: Robbins files pat. on short pulse receiver
- 1972: Morey files pat. on ground penetrating radar
- 1978: Cronson files pat. on collision avoidance system
- 1978: Bennett & Ross published survey of "Time Domain Electromagnetics…" in IEEE Proceedings



About 25 years ago…



"… BA[seband]R[adar] have been … recently demonstrated for various applications, including auto precollision sensing, spaceship docking, airport surface traffic control, tanker ship docking, harbor collision avoidance, etc. These sensing applications cover ranges from 5 to 5000 ft.

… Further applications resulted in the construction of a sub-nanosecond, single coaxial cable scheme for multiplexing data between computer terminals … . More recently baseband pulse techniques have been applied to the problem of developing a short-range wireless communication link. Here, the low EM pollution and covertness of operation potentially provide the means for wireless transmission without licensing."

from the Abstract of C. L. Bennett and G. F. Ross, "Time-Domain Electromagnetics and Its Applications," *Proc. of the IEEE*, Vol. 66, No. 3, pp. 299-318, Mar. 1978

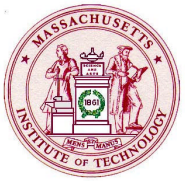
"these ideas" began ~40 years ago…

"… We also wish to acknowledge the guidance and encouragement of both Professor Athanasios Papoulis of the Polytechnic Institute of New York and Professor Walter Weeks of Purdue University where these ideas began… "

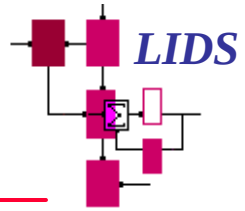
from the Acknowledgement of C. L. Bennett and G. F. Ross, "Time-Domain Electromagnetics and Its Applications," *Proc. of the IEEE*, Vol. 66, No. 3, pp. 299-318, Mar. 1978

"The author wishes to acknowledge the assistance given him by Prof. A. Papoulis, Polytechnic Institute of Brooklyn, who guided the initial study. … "

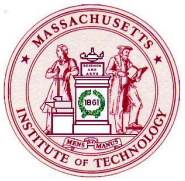
from the Acknowledgement of G. F. Ross, "The Transient Analysis of Certain TEM Mode Four-post Networks," *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-14, No. 11, pp. 528-542, Nov. 1966



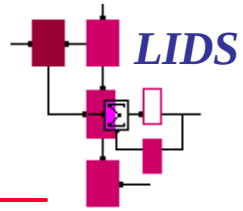
Recent Activities



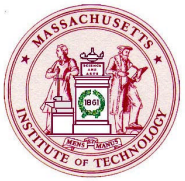
- 1990's: Efforts on UWB communication theory, experimentation, and practice
  - ✓ First UWB signal propagation experiments
  - ✓ First statistical UWB propagation channel model
  - ✓ Demonstrated UWB signal's resolvability in dense multipath environments & its unique immunity from fading, thus confirming that only a small fading margin is required to guarantee reliable communications
    - ⇨ Robustness of a UWB signal in a multipath environment
  - ✦ Win and Scholtz, "Impulse radio: How it works," IEEE Commun. Lett., vol. 2, no. 2, pp. 36-38, Feb. 1998.
  - ✦ Win and Scholtz, "On the robustness of ultra-wide bandwidth signals in dense multipath environments," IEEE Commun. Lett., vol. 2, no. 2, pp. 51-53, Feb. 1998.
  - ✦ Win and Scholtz, "On the energy capture of ultra-wide bandwidth signals in dense multipath environments," IEEE Commun. Lett., vol. 2, no. 9, pp. 245-247, Sept. 1998.

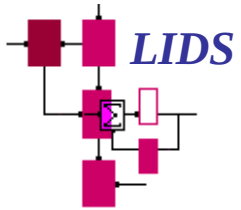


Recent Activities



- 1995: First UWB Radio Lab was formed with support from Industry
- May 1998: FCC announces upcoming NoI
- May 2000: FCC announces NPRM on UWB radiation
- Feb. 2002: FCC approves Report and Order on UWB emissions
- 2002: availability of UWB components on chips announced
- May 2002: first all-UWB Conference
- Dec. 2002: more than 500 paper on UWB published
- 2002: IEEE established Task group (802.15.3a) for UWB-based high-data rate physical layer standard for PANs (Personal Area Networks)
  - Call for proposals 11/02, 24 proposals presented 03/03, vote for draft proposal 09/03, Final version late 2003
- Task group for low-data-rate (802.15.4a) UWB system under discussion

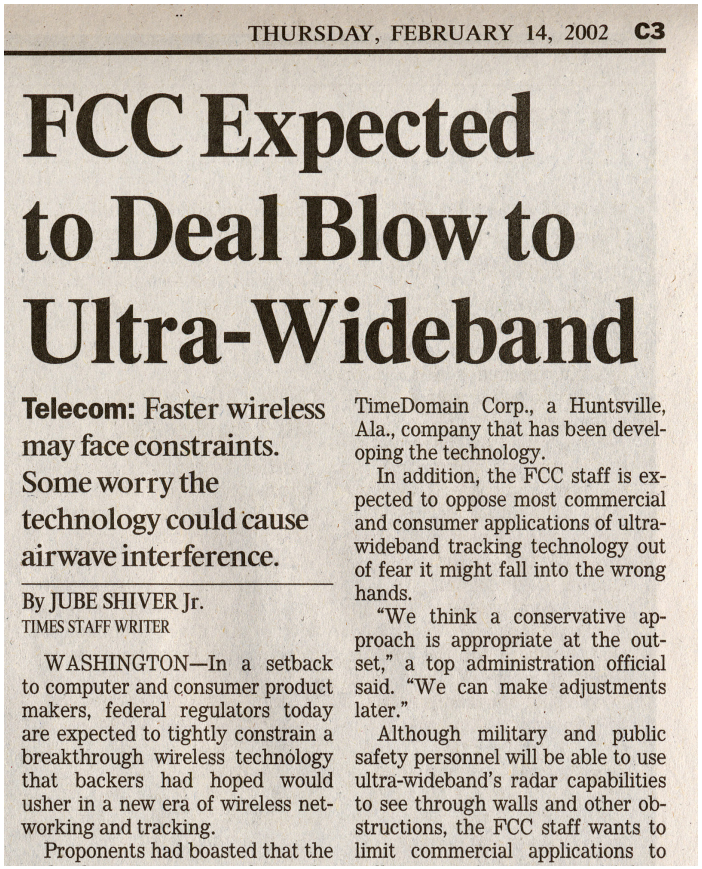




FCC Regulations

Know Thy ~~Channel~~ Rules

FCC Decision 2/14/02



THURSDAY, FEBRUARY 14, 2002 C3

FCC Expected to Deal Blow to Ultra-Wideband

Telecom: Faster wireless may face constraints. Some worry the technology could cause airwave interference.

By JUBE SHIVER Jr.
TIMES STAFF WRITER

WASHINGTON—In a setback to computer and consumer product makers, federal regulators today are expected to tightly constrain a breakthrough wireless technology that backers had hoped would usher in a new era of wireless networking and tracking.

Proponents had boasted that the TimeDomain Corp., a Huntsville, Ala., company that has been developing the technology.

In addition, the FCC staff is expected to oppose most commercial and consumer applications of ultra-wideband tracking technology out of fear it might fall into the wrong hands.

"We think a conservative approach is appropriate at the outset," a top administration official said. "We can make adjustments later."

Although military and public safety personnel will be able to use ultra-wideband's radar capabilities to see through walls and other obstructions, the FCC staff wants to limit commercial applications to

Happy Valentine's Day

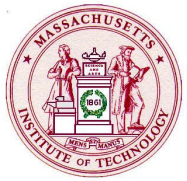
FCC Approves New Wireless System

Federal regulators approved the use of a new wireless technology that could help rescue workers find people buried in rubble or locate stresses in the side of a bridge, overcoming fears it would interfere with important navigation aids.

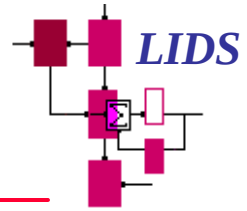
The Federal Communications Commission voted unanimously to approve limited use of ultra-wideband technology for hand-held wireless communications, ground-penetrating radar and vehicle collision avoidance systems.

The FCC approved the marketing and operation of products using UWB technology but limited it to the range above the 3.1-gigahertz frequency and, in some cases, restricted use to law enforcement, scientific researchers and certain industries such as construction.

Reuters



Regulations and Opportunities



- UWB defined as $2(f_H-f_L)/(f_H+f_L) > .20$
  at -10 dB points f_H and f_L
- 500 MHz minimum instantaneous BW per transmission
- Power spectral density limit (- 41.3 dBm/MHz),
- Peak power limits
- Starting point for communications systems
  - 7.5 GHz of new, unlicensed spectrum
    - Spectral mask from 3.1-10.6 GHz
    - Signals must satisfy prescribed power spectral density masks for different classes of operations (Different indoor/outdoor masks)
  - No legacy limitations or backward compatibility requirements

More Regulatory Restrictions

Use in electronic toys not permitted.

Operation on airplanes, ships, and satellites not permitted.

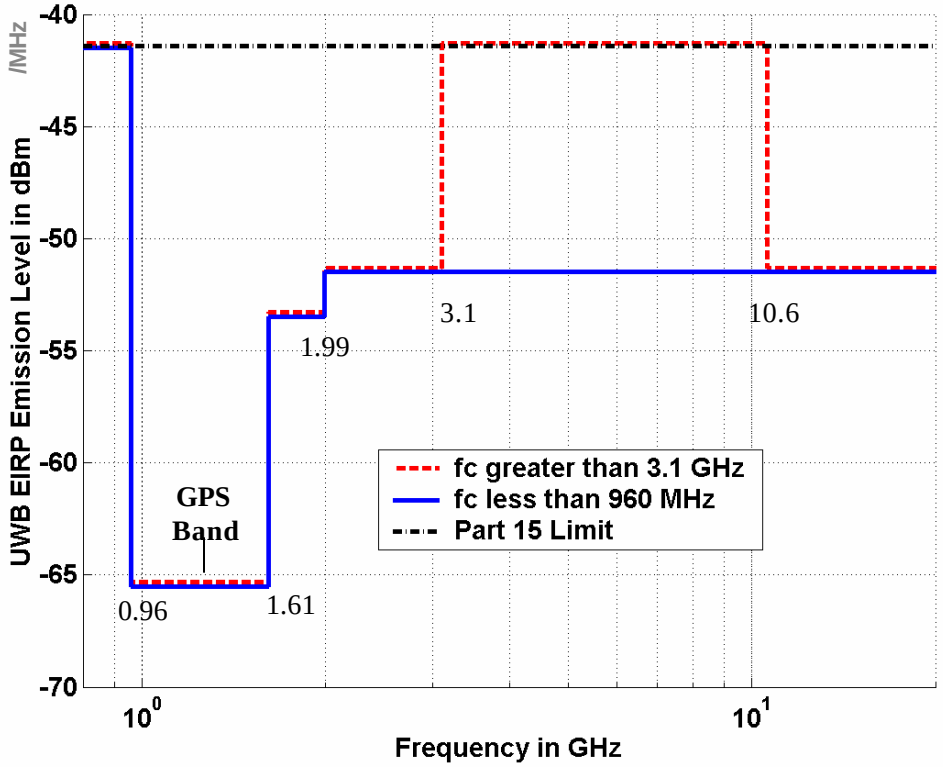
FCC UWB Device Classifications

FCC 1st Report and Order Authorizes Five Classes of Devices

Class / Application	Frequency Band for Operation at Part 15 Limits	User Limitations
Imaging: Ground Penetrating Radar, Wall, Medical Imaging	<960 MHz or 3.1 to 10.6 GHz	Yes
Imaging: Through-wall	<960 MHz or 1.99 to 10.6 GHz	Yes
Imaging: Surveillance	1.99 to 10.6 GHz	Yes
Communications and Measurement Systems	3.1 to 10.6 GHz (different "out-of-band" emission limits for indoor and outdoor devices)	No
Vehicular	24 to 29 GHz	No

UWB Emission Limits

GPRs, Wall Imaging, & Medical Imaging Systems

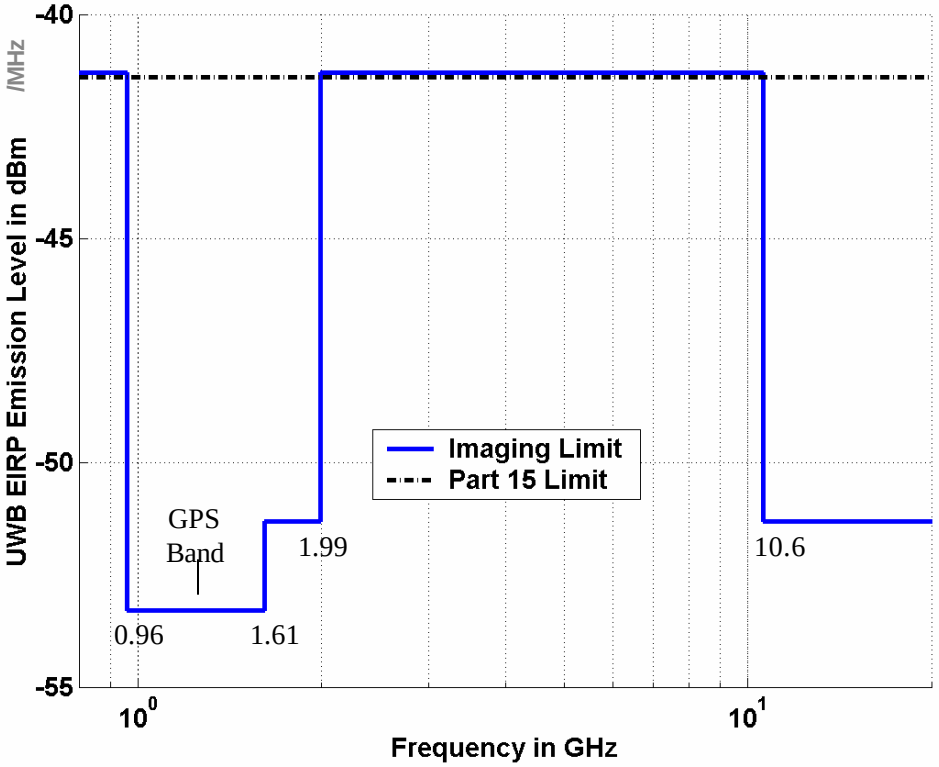


Operation is limited to law enforcement, fire and rescue organizations, scientific research institutions, commercial mining companies, and construction companies.

http://www.fcc.gov

UWB Emission Limits

Thru-wall Imaging & Surveillance Systems



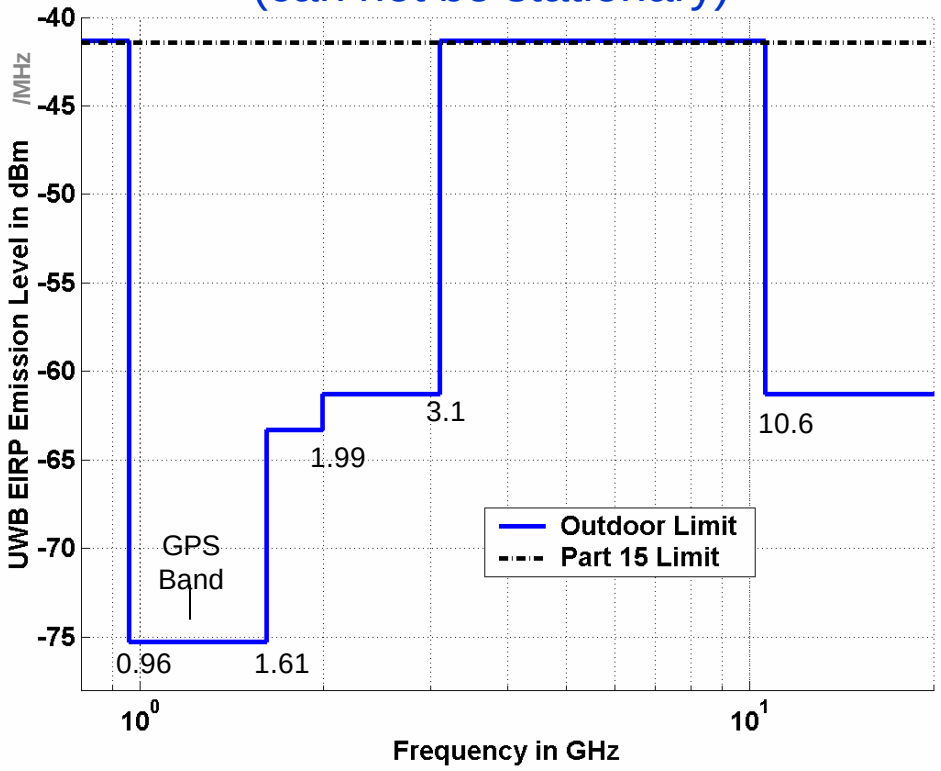
Operation is limited to law enforcement, fire and rescue organizations. Surveillance systems may also be operated by public utilities and industrial entities.

http://www.fcc.gov

UWB Emission Limits

Outdoor Hand-held Systems

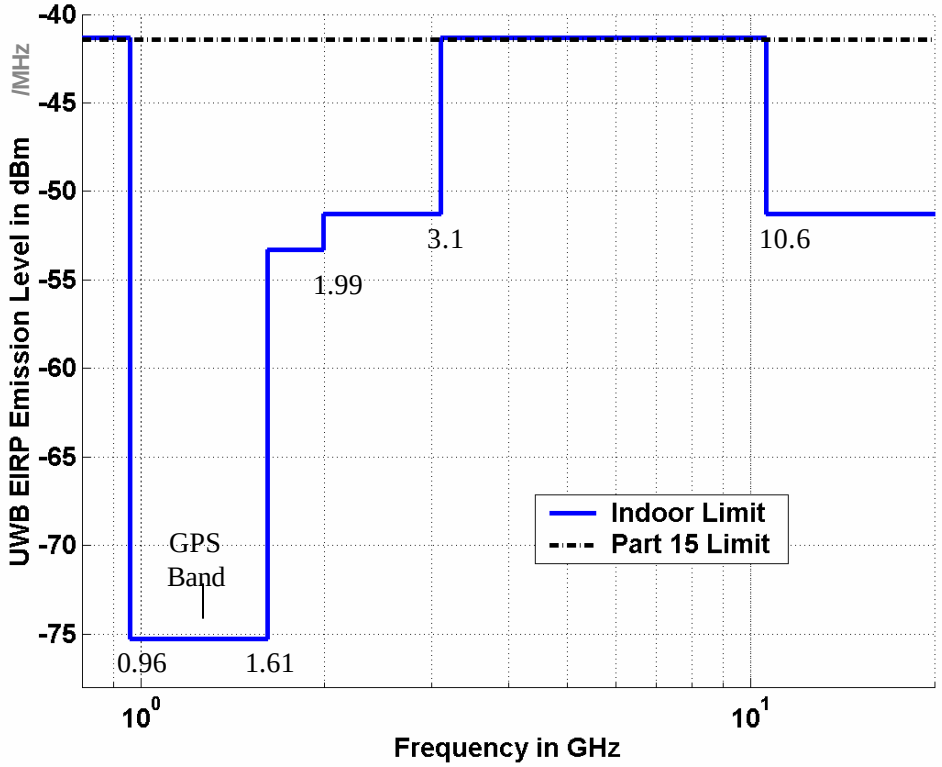
(can not be stationary)



http://www.fcc.gov

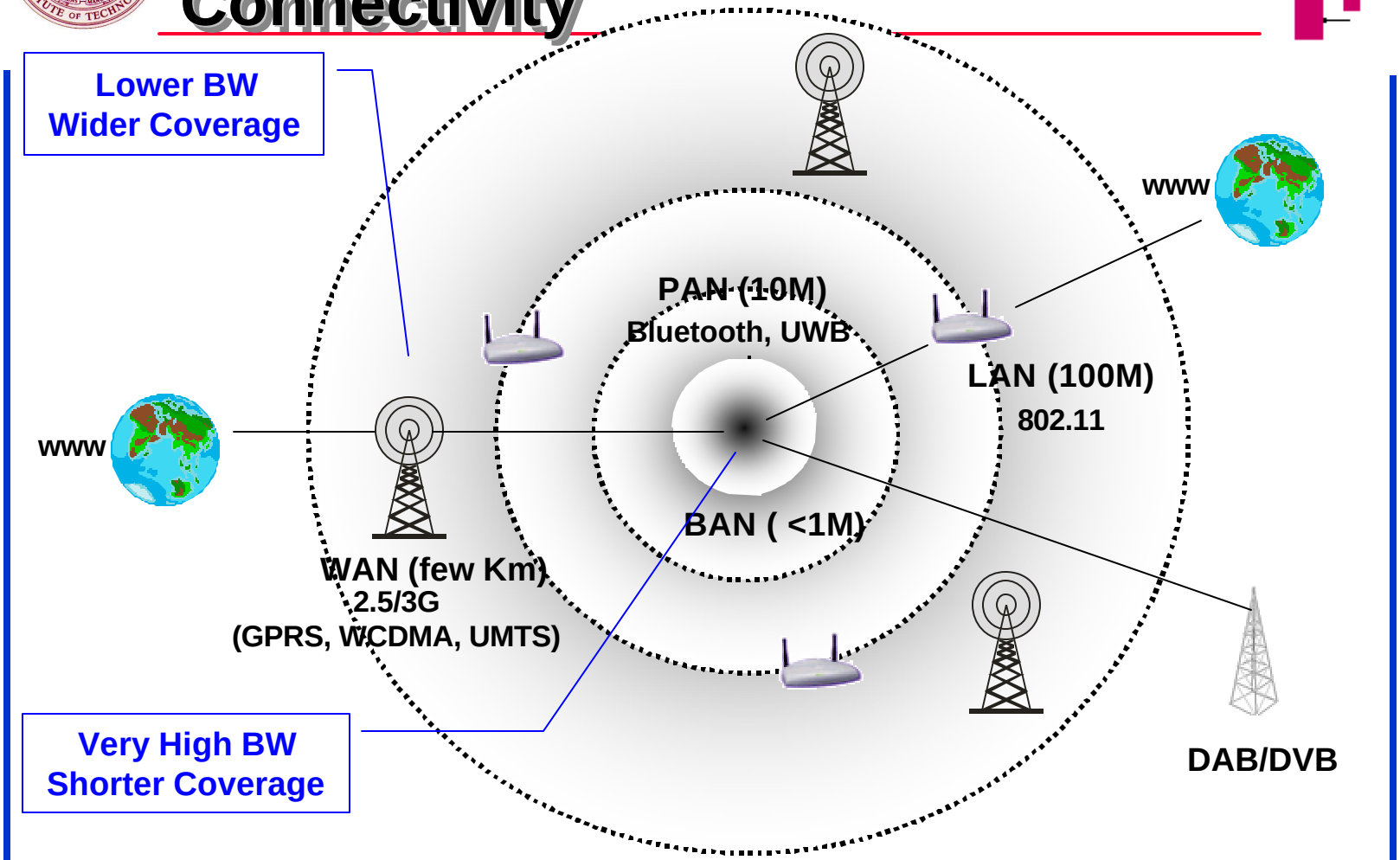
UWB Emission Limits

Indoor Systems



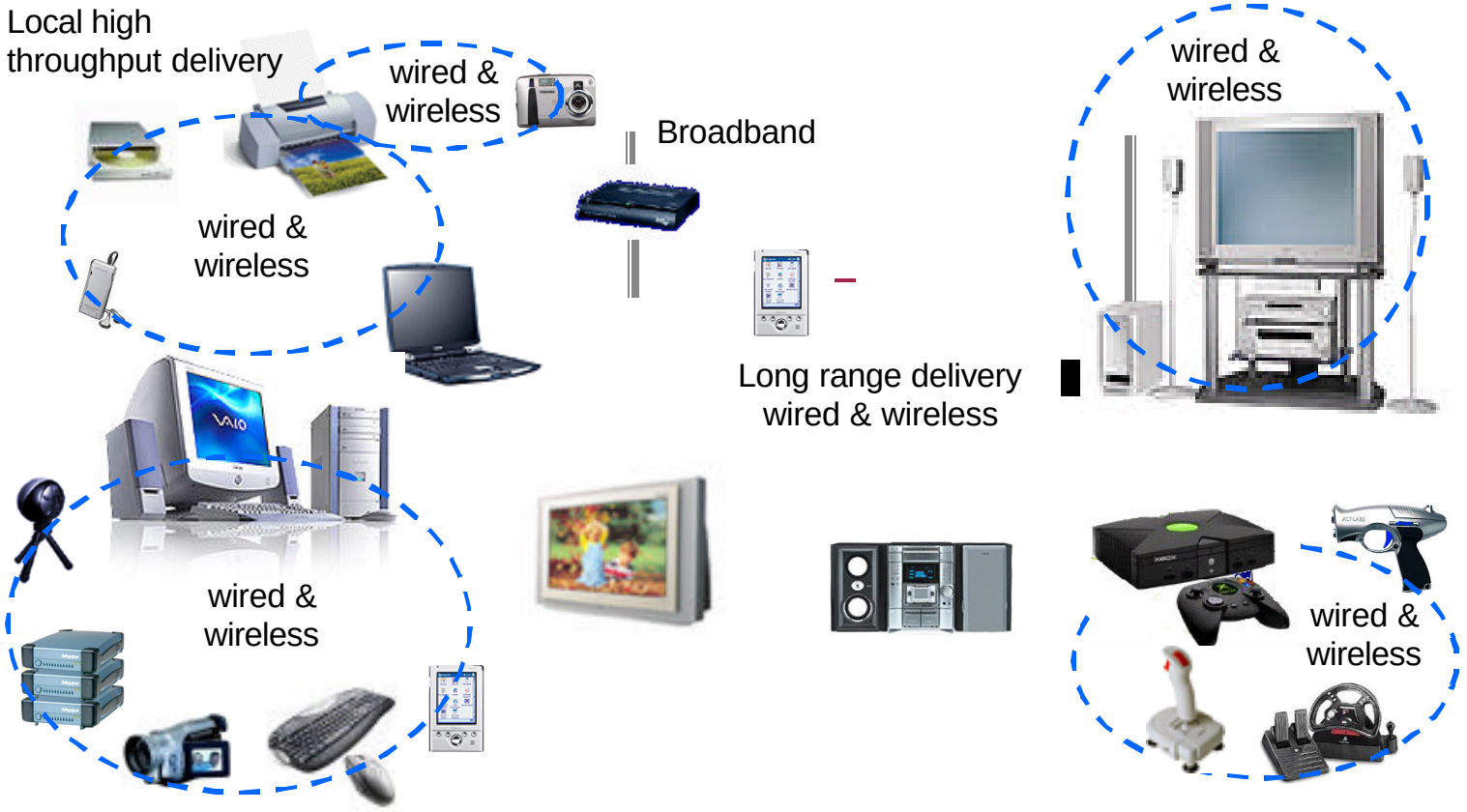
http://www.fcc.gov

Evolution of Wireless Connectivity

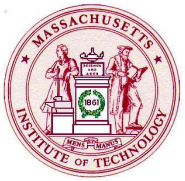


Concentric Spheres of Interconnected Wireless Networks

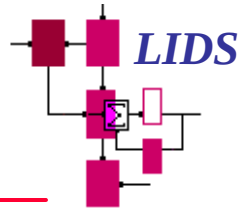
UWB Usage Models



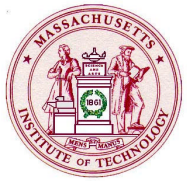
UWB complements longer range access technologies



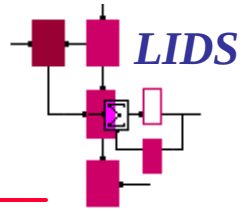
UWB system requirements



- Peak throughput of - 110 Mbps @ 10 m
  - 200 Mbps @ 4-6 m
  - 480 Mbit/s at shorter distances
  - Low latency, large file transfer (videos, pictures, disk backup, etc.
- Coexistence
  - Needs to work with other wireless systems
    (e.g. 802.11a/b/g/n WLAN systems)
  - UWB (as overlay approach) needs to be proven not to cause harmful interference
  - Regulatory challenges still exist (inside/outside US)
  - Needs to adapt to future spectrum allocations and new spectrum usage models

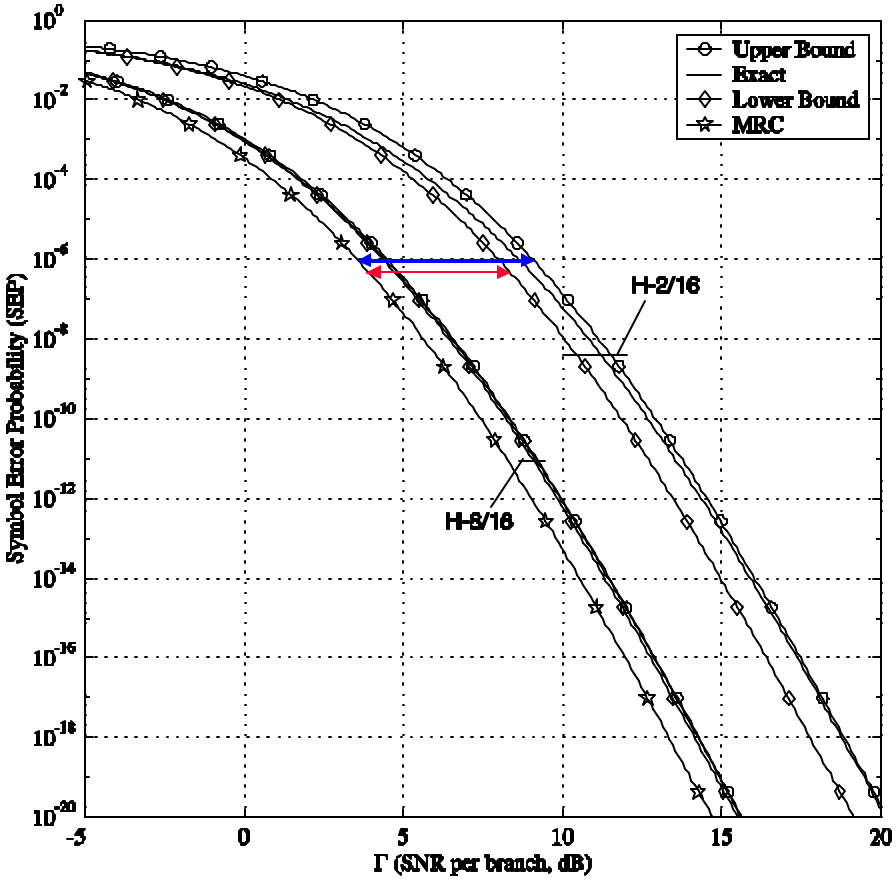


IEEE 802.15.3a proposals

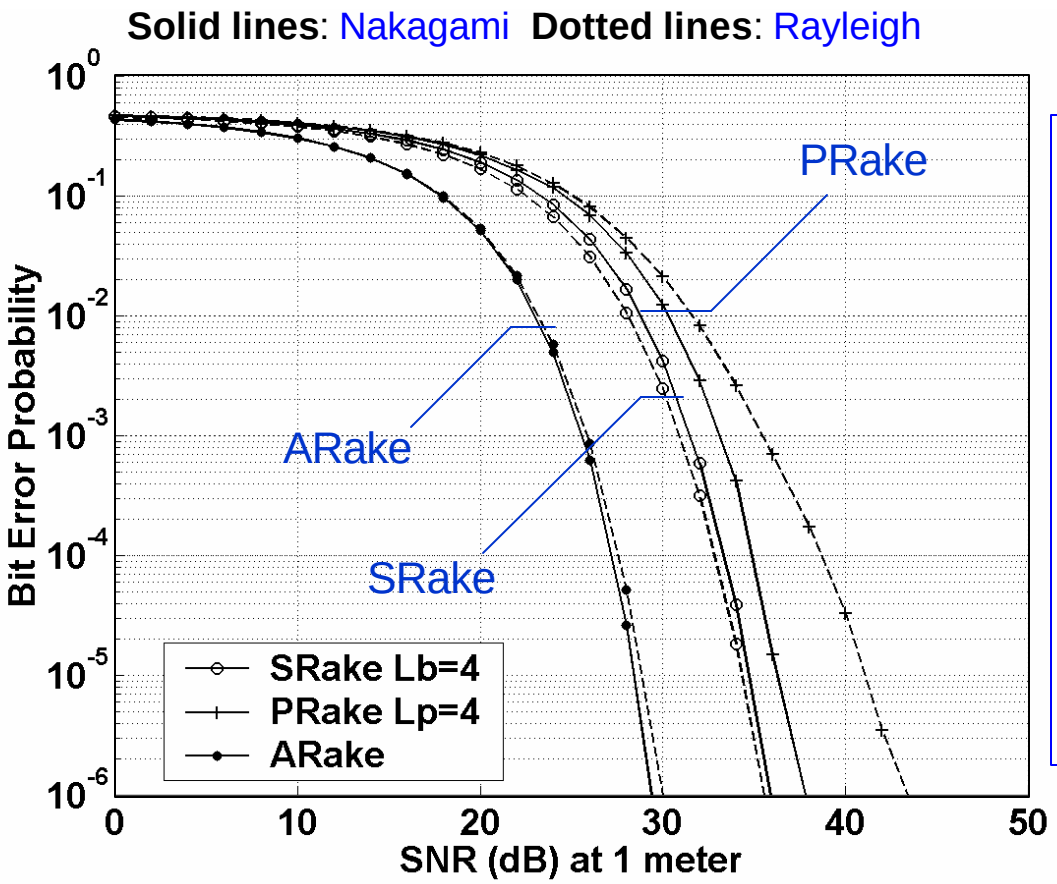


- 24 proposals submitted (31 intended)!
  - Impulse Radio
    - Single impulse occupies 3.1-10.6 GHz
  - Single-carrier based
    - Divide spectrum in 2-3 bands (~2-4 GHz BW), use 1 band at a time
      - > 1 band used with parallel transmission
    - DS-CDMA + FDMA w/ 2-3 channels
  - Multi-carrier (Multi-band) based
    - Divide spectrum into > 3 bands (500-700 MHz BW or variable BW)
    - Enable switching/hopping between bands serially in time
    - Pulsed or OFDM (TI) modulation within ~500 MHz band

Tight Simple Bounds

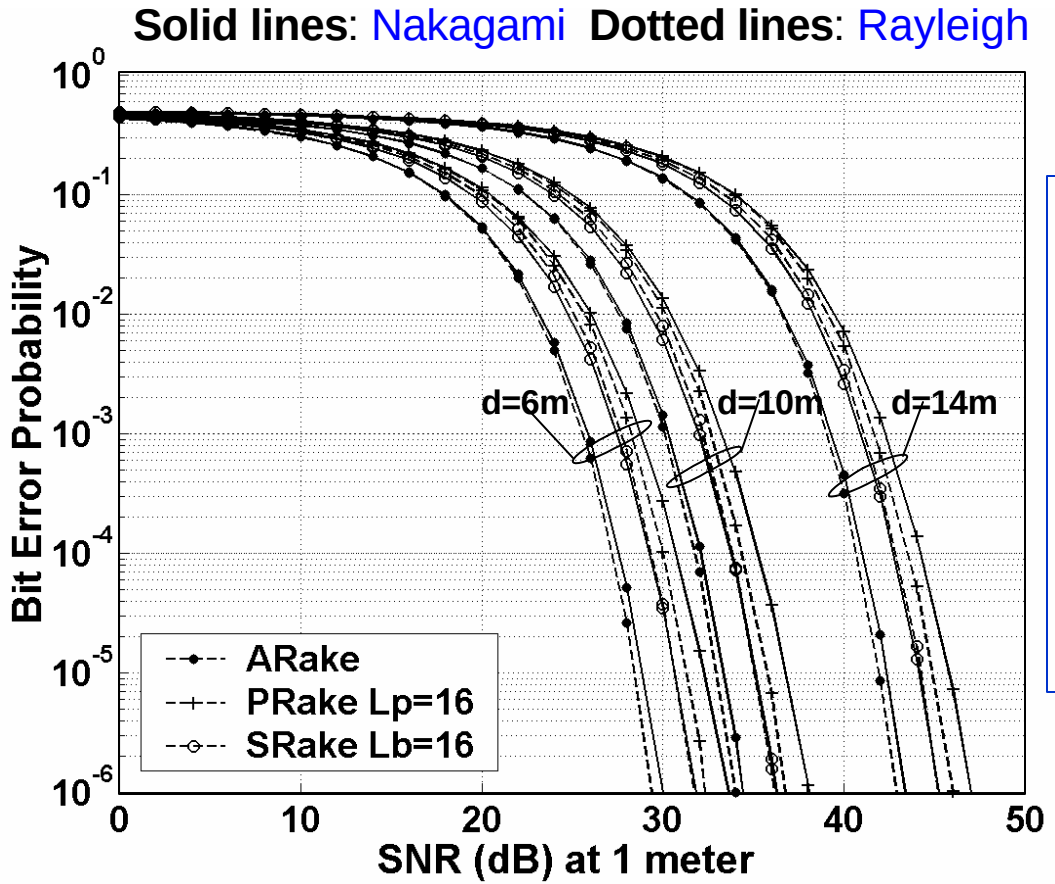


Rake Receivers Comparison – L = 4

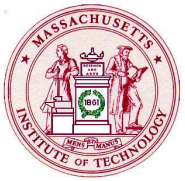


- ARake and SRake are Not Sensitive to Channel Model
- PRake Performs Better in the Realistic UWB (Nakagami) Channel

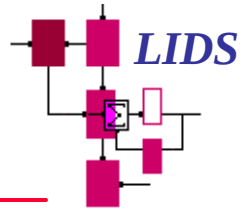
Rake Receivers Comparison – L = 16



- Simpler PRake Perform almost as Good as SRake in Realistic UWB Channel



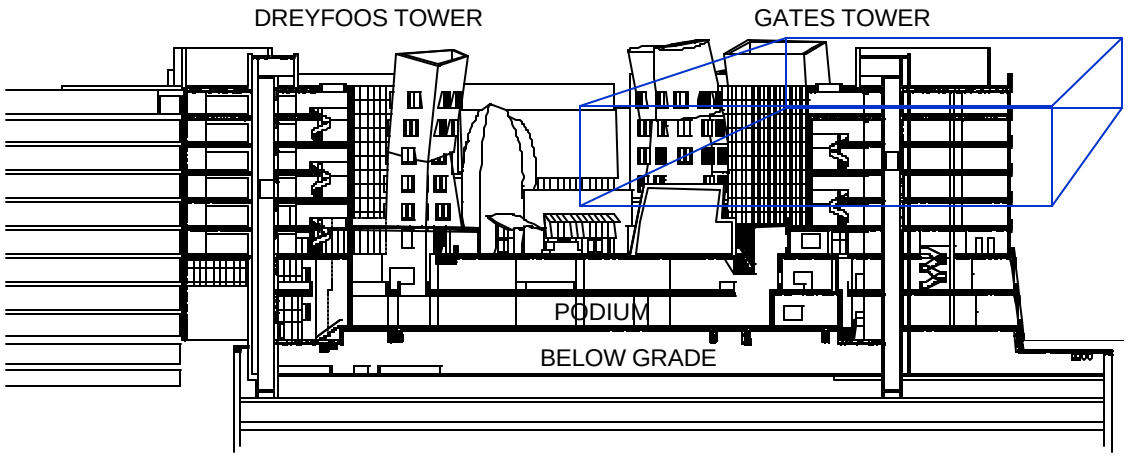
UWB Issues



- UWB Channles
- UWB Networks
- Low Complexity “cheap” transceivers
- Position Location and Ranging
- Rapid Algorithms
- Coexistence Issues
- Interference Aggregation
- Future Spectrum Usage
- Theoretical Issues, Feedback, …..

New Facility-2003

- State of the Art Laboratory for Wideband Wireless Channels and Systems Characterization, Modeling, Designing, Testing, and Innovation
- Laboratory and Offices for Faculty, Students and Visiting Scholars



The MIT Ray and Maria Stata Center

Summary

- wideband envisioning Wireless Innovation Group
  - creates a nucleus of activities, centered around LIDS at MIT, attracting world-class researchers for collaborations
  - Fundamental contributions to communication theory, multiple antennas systems, diversity methods and MIMO systems
  - Pioneering analytical and experimental advances, and outstanding leadership that created the ultra-wide bandwidth industry