UWB Radio Technology

The Global View of a Wireless System Integrator

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The Promises (?) of UWB Radio Technology

Typical Statements made by Developers or the Press

"UWB is **extremely simple** and **very cheap** to implement"

"Know the distance from pin to cup within 2 cm"

"UWB systems can be very adaptive, using different frequencies as circumstances require"

"UWB is a very natural fit with another new technology: Software Defined Radio (SDR)"

"Only one wireless technology **simultaneously offers low cost, low power consumption, and the data rates** necessary to support multiple streams of digital video and/or audio"

"Common and nearly all-digital architecture for communications, radar, and positioning"

"Potential for **extremely large data rates** over short distances >>> "Today: 60Mb/s; in 18 Months: **>100Mb/s**"

"Ultra Wideband – **Megabits at Microwatts**"

"Aggregation effects will not cause significant interference"

"High data rate for communications … UWB could transform wireless networking"

"UWB technology can be integrated into low-cost, low power, and high-performance devices"

"Ultra-wideband is in its infancy in terms of speed and distance, … but **there's no reason why you can't increase speed and distance**"

"High range resolution capability"

"UWB could have a dramatic impact on short-range wireless communications for the enterprise"

"Extremely difficult to intercept – UWB is more secure than any of the [IEEE] 802.11's"

The Promises (?) of UWB Radio Technology

Example of a Challenging Wireless System Integration Problem

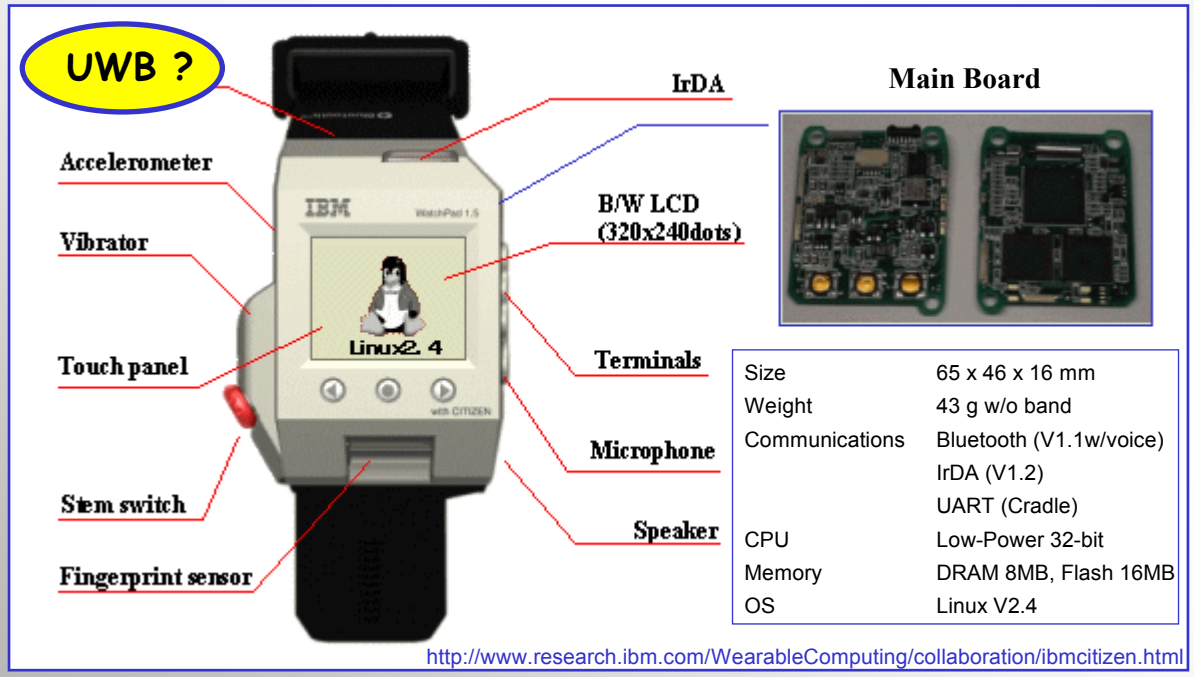
Linux Watch: Only Time Will Tell

CNET News.com, October 11, 2001, (http://news.cnet.com)

"… includes a *Bluetooth* chip for wireless communication with notebooks, handheld computers, and cell phones."

"Designers have been challenged by the limited amount of real estate inside wristwatches for processors, memory, and other components … *battery power has also been a constraint*."

… is this perhaps a case for UWB ?



Size	65 x 46 x 16 mm
Weight	43 g w/o band
Communications	Bluetooth (V1.1w/voice)
	IrDA (V1.2)
	UART (Cradle)
CPU	Low-Power 32-bit
Memory	DRAM 8MB, Flash 16MB
OS	Linux V2.4

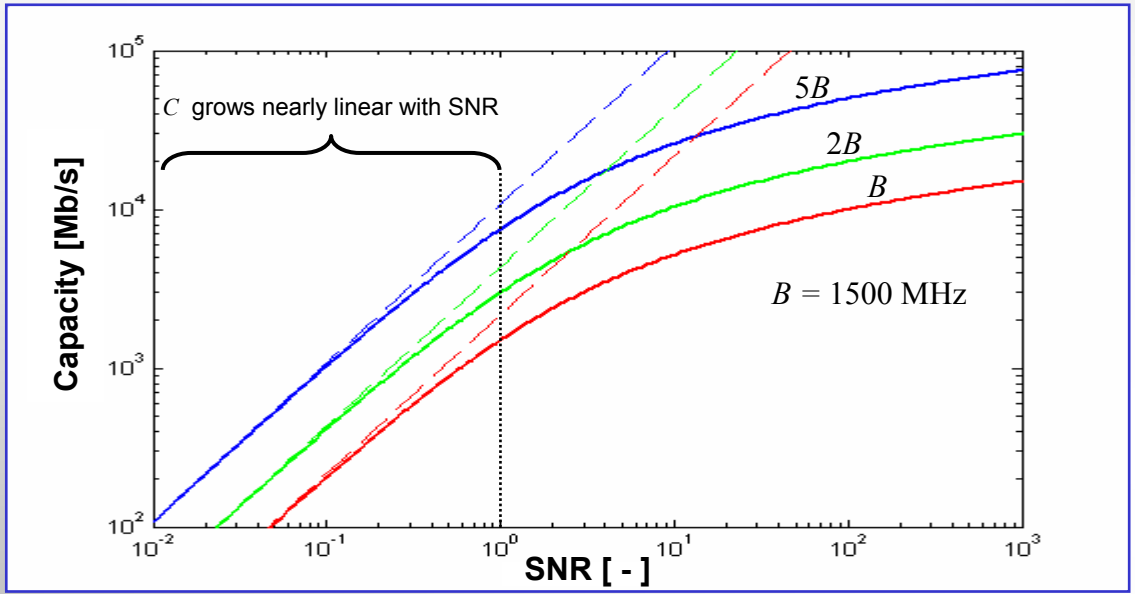
http://www.research.ibm.com/WearableComputing/collaboration/ibmcitizen.html

The Promises (?) of UWB Radio Technology

The Bandwidth Argument

- Wireless system design is a tradeoff between data rate [b/s], range [m], and transmitter power [W]. The achievable data rate is limited by the channel bandwidth (B, [Hz]) and the resulting signal-to-noise ratio (SNR, [-]) at the receiver.
- Proponents of UWB-RT often argue with the theoretical maximum data rate – the channel capacity (C, [b/s]) – i.e., assuming the ideal additive white Gaussian noise channel (AWGN), they cite the Hartley-Shannon law to indicate the data rate potential of UWB-RT:

$$C = B\log_2(1+SNR) \le B\,SNR\log_2(e)\ , \quad [\text{b/s}]$$



Estimating Achievable Data Rates for UWB Radio Systems

Channel Capacity vs. Cutoff Rate for the UWB-AWGN Channel

Cutoff Rate [b/use]: $R_o = -\log_2\left(\min_{\{p_k\}} \sum_{i=1}^{M}\sum_{j=1}^{M} \exp\left[-\left(\frac{D_R}{4N_0}\right)\left(\frac{NB}{F_{PRF}}\right)\left\|\bar{s}_i - \bar{s}_j\right\|^2\right] p_i\, p_j\right)$; $\bar{s}_k = \frac{s_k}{\sqrt{\bar{E}_S}}$, $\forall k$; $\sum_{k=1}^{M} p_k = 1$

Symmetric Cutoff Rate [b/s]:

$$\tilde{R}_o \triangleq \left(\frac{F_{PRF}}{N}\right) R_o \Big|_{\{p_k = \frac{1}{M}\}}$$

Channel Capacity [b/s]:

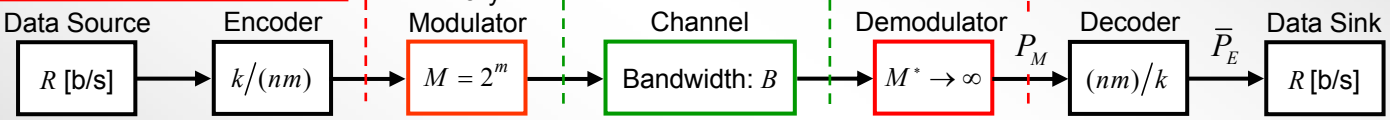
$$C = B\log_2\left[1 + \left(D_R/N_0\right)\right]$$

Block Codes (Dimension n):

$$\bar{P}_E \le 2^{-n\left(R_o - R_C\right)},\ R_C = k/n < R_o$$

Convolutional Codes (Constraint n):

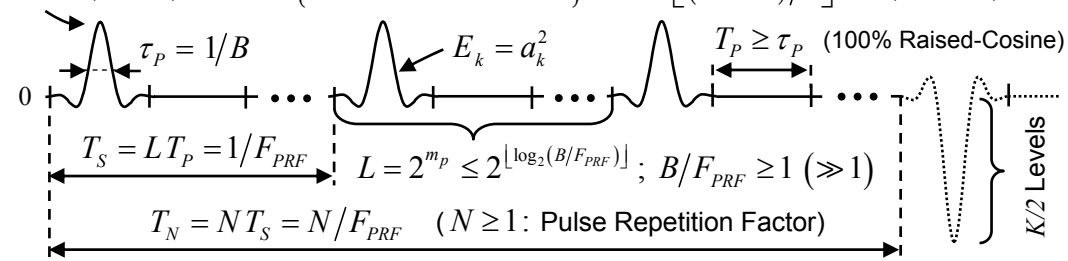
$$\bar{P}_E \le c_{R_C} 2^{-nR_o},\ R_C = k/n < R_o$$

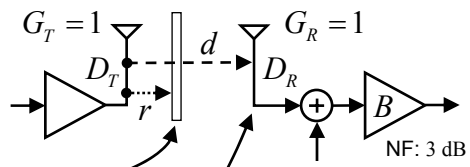


Example Bi-Phase K-PAM / L-PPM: $K = 2^{m_a}$; $L = 2^{m_p}$; $M = 2^m = KL = 2^{(m_a + m_p)}$

$$\left\{\boldsymbol{s}_i = \left(s_{i,1},\ldots,s_{i,j-1},s_{i,j},s_{i,j+1},\ldots,s_{i,L}\right) = \left(0,\ldots,0,s_{i,j} = a_k,0,\ldots0\right);\ i = 1,2,\ldots,M\right\}$$

$$a_k = \pm\left(2k-1\right)\sqrt{\varepsilon},\ k \in \left\{1,2,\ldots,K/2\,;\,K = 2^{m_a}\right\},\ \bar{E}_S = \left[\left(K^2-1\right)/3\right]\varepsilon = \left(B/F_{PRF}\right)D_T$$





$$\alpha\left(d,r\right) = G_T G_R \beta_W(r)\left(\frac{3\times10^8}{4\pi f_C d}\right)^2$$

$$D_R = \alpha\left(d,r\right)D_T\ ;\ f_C = 6.85\,\text{GHz}$$

$$D_T G_T = 75\ \text{nW/MHz (FCC)}$$

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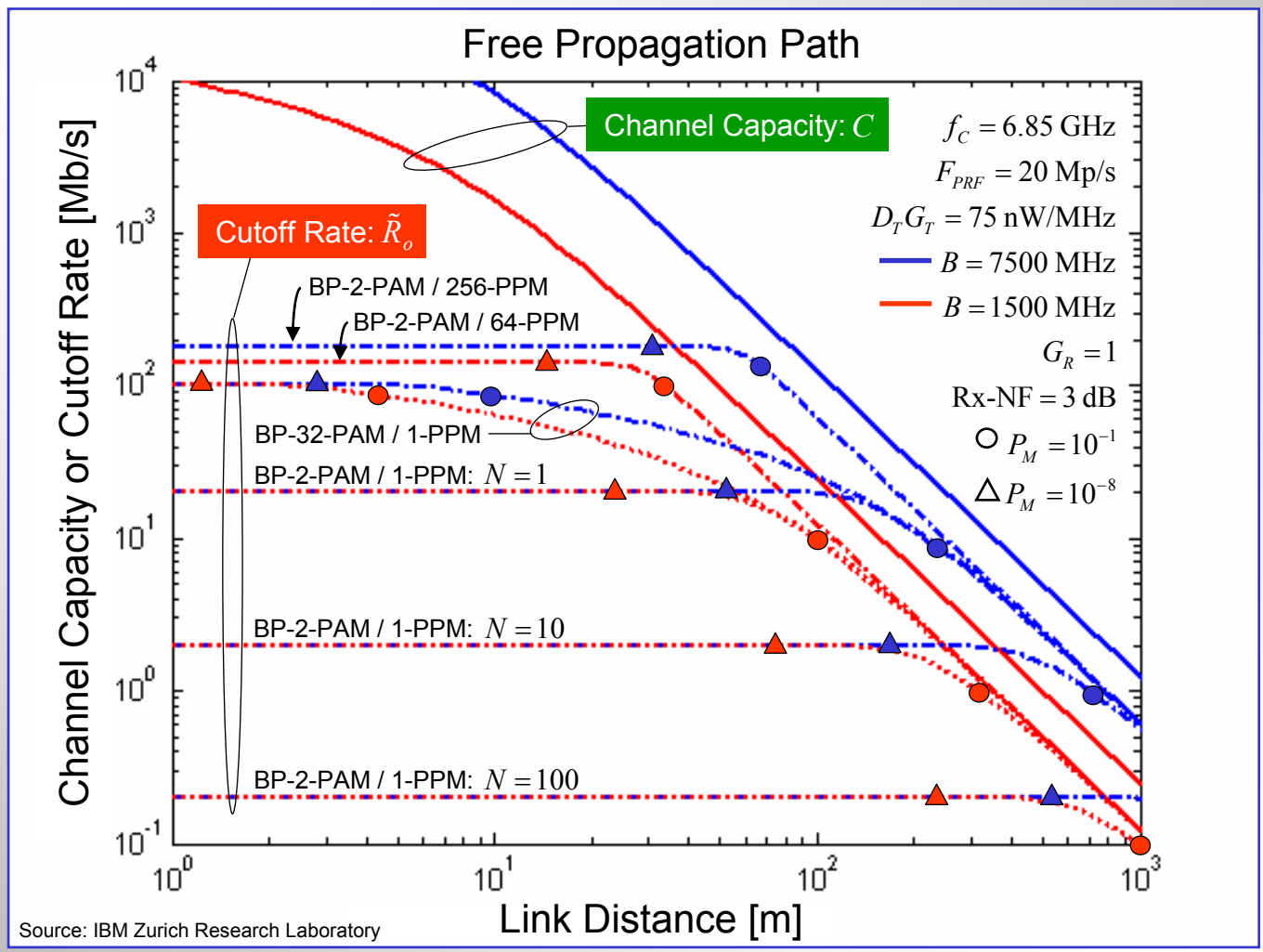

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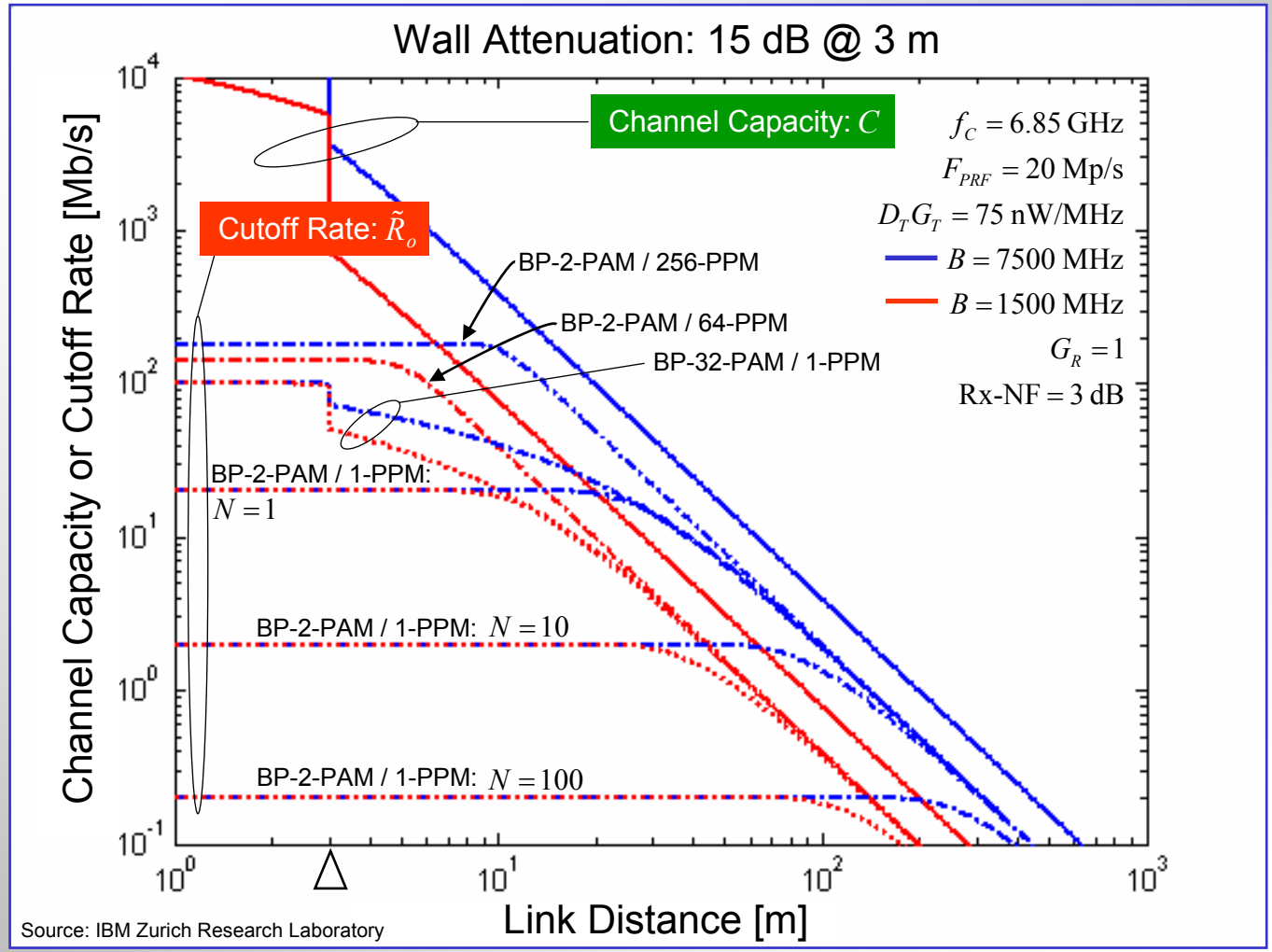

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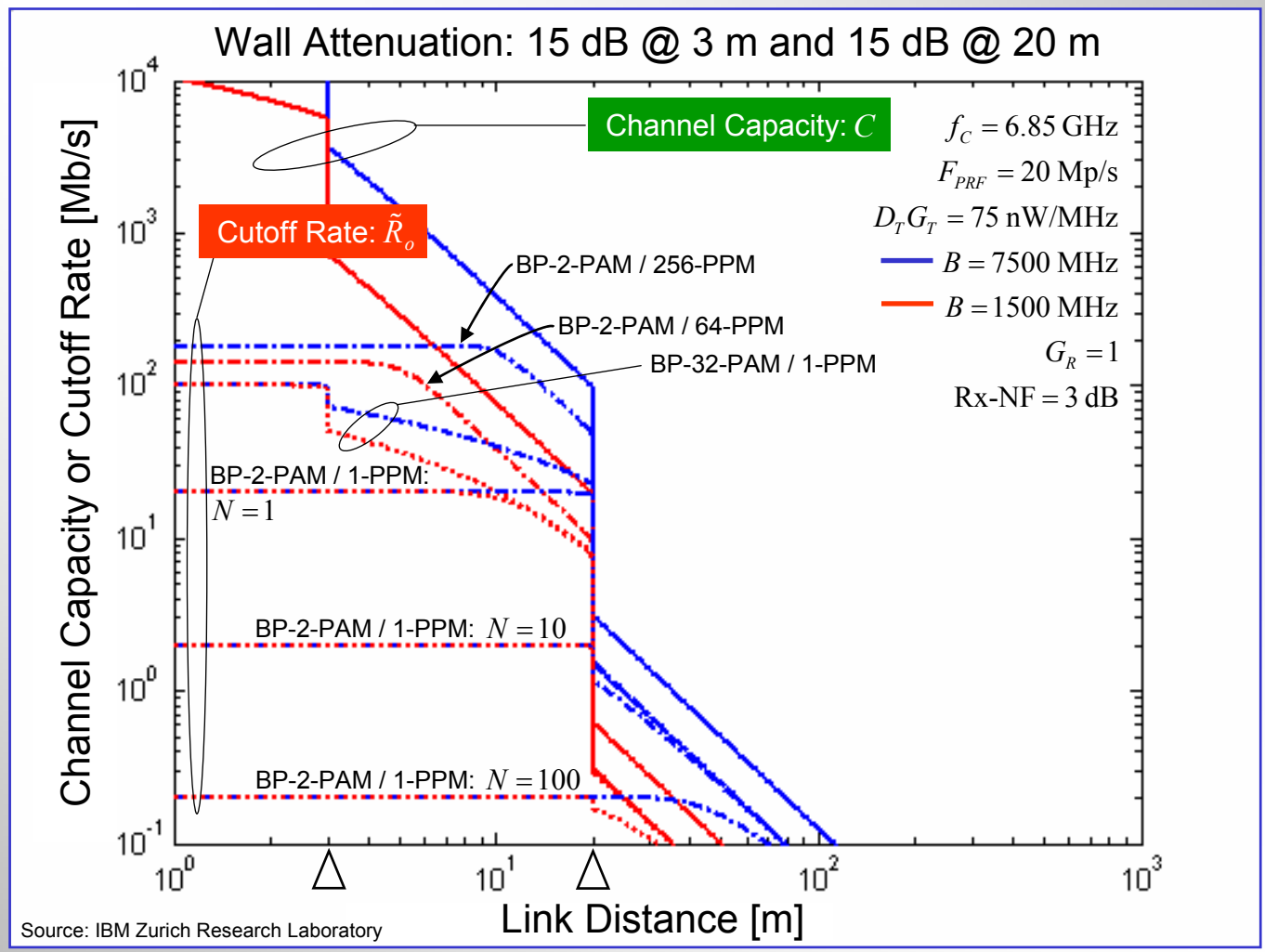


The View of a Wireless System Integrator

Defining the Viewpoint

- There are three relevant categories of wireless technologies:
  - **Personal Area Networks (PAN) -** Optimized for short-range low power communications between personal devices such as cell phones, PDAs, and PCs, with a range of up to 10 m.
  - **Wireless Local Area Networks (WLAN) -** Networks optimized for wireless Ethernet packet data transmission with a maximum range of 50 to 100 m.
  - **Wide Area Networks (WAN) -** Cellular networks designed to transmit voice and data over relatively long distances. WAN technology generations: 1G (analog technology), 2G (switched digital networks), and 2.5G or 3G (emerging voice and packet data networks, UMTS).
- Adoption of a wireless technology is driven by the interaction of three major factors:
  - **Technology -** Today's dominant technology driver in the wireless arena is the rapidly increasing performance of low cost digital signal processors. This increase in signal processing capability allows increasingly sophisticated wireless algorithms, enabling wireless solutions to better exploit theoretical channel limits.
  - **Regulations -** Government regulations define available spectrum, maximum power levels, band sharing rules, and often define specifics of the coding and modulation schemes allowed within a frequency band. Thus, regulations may impede the application of new signal processing capabilities. Specific regulations often apply to regions only, making it more difficult to design a single cost-efficient solution for a global market.
  - **Standards -** Even when new technologies and/or government regulations potentially enable better or new solutions and applications, customer requirements demand interoperable solutions based on widely (and preferably globally) accepted industry standards.

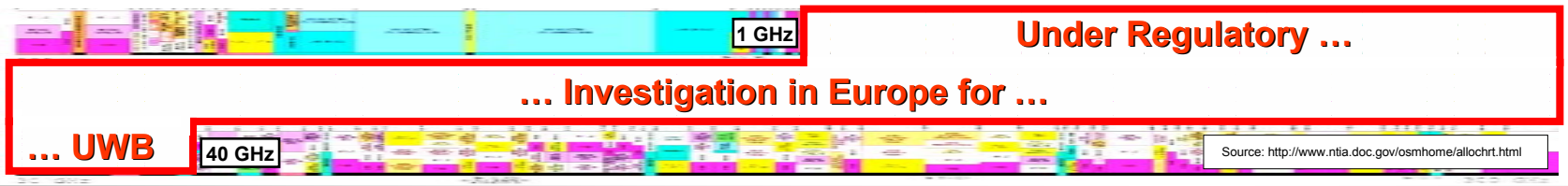
- New wireless technologies offer opportunities for a wireless system integrator to improve the user experience and help create the user perception of a (global) seamless wireless infrastructure (i.e., >3G).
- Wireless system integrators trying to cover the global market are challenged because of the different and competing regional standards and technologies >>> this situation will persist for some time to come.

The View of a Wireless System Integrator

Regulatory Issues are of Global Importance for UWB-RT

- ***United States of America***
  - Present Status: FCC approved a ***First Report and Order*** (2/14/2002) ››› NNPRM (?).
- ***Asia (Japan)***
  - Will the MPT in Japan harmonize its future UWB rules with those issued by the FCC **?**
  - There is presently little information available from other countries.

- ***Europe***
  - CEPT (SE24) and ETSI (TG31A/B) - "*Generic UWB Systems*" (TRxxx Document):
    → Define spectrum sharing mechanisms and constraints to protect other *Radio Services,*
    → SE24 - Presentation of preliminary results at 2nd CEPT/UWB-Workshop (04/11/02).



- ***ITU-R (Radiocommunication Sector)***
  - Working Party 8A (WP8A) - Started work based on introduction of "*Question on UWB:*"
    → Compatibility between UWB emissions and (land mobile) radiocommunication services?

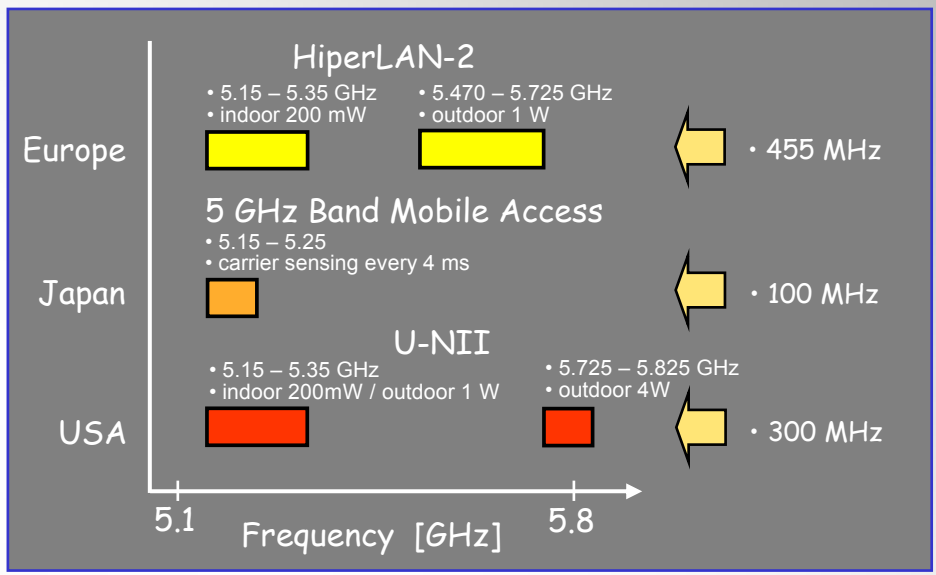
The View of a Wireless System Integrator

Regulatory Issues are of Global Importance – The 5 GHz WLAN Example

- Problems Induced by Regional Thinking …

"Single Wireless LAN Spec in Peril"
(EE Times: 10/01/01, 12:52 p.m. EST)
http://www.eetimes.com/story/OEG20010928S0099

- Barriers emerge in Europe and Japan to block adoption of IEEE-802.11a.
- Some 802.11a supporters are coming to accept a three-standard world.
- Many national regulators have not yet opened up the spectrum for the use of wireless (radio) LANs at all.
- 5.470 – 5.725 GHz is not allocated for Radio LANs in the USA (see also below).



- … Force Global Efforts to Remedy the Situation:

- OEMs operating on a global scale are demanding a single, flexible platform which supports the different regional standards for WLANs ››› user-friendly (cost-effective?) "Global Wireless LAN."
- There are current efforts to align the 5-GHz U-NII allocation in the USA with that of Europe as part of a worldwide move for global harmonization of spectrum assignment ››› WECA petition to FCC (01/15/02).

→ Ideally, the required spectrum harmonization can be agreed on in time for the WRC 2003, because …

→ … a harmonized spectrum allocation at 5 GHz would help 802.11a's worldwide adoption and provide a more user-friendly platform for the emerging next-generation (high-speed, 54 Mb/s) WLAN.

Standardized or Proprietary Commercial PHY/MAC Solutions?

The Intended Application may Provide the Answer

- Proprietary solutions possible for …
  - RF tagging/identification
  - Intrusion detection
  - Ground penetrating radar
  - Collision/obstacle avoidance sensors
  - Dedicated precision ranging
  - Industrial RF monitoring systems
  - Medical and hospital applications
  - LPI/D communication systems
  - …

→ Mainly (stationary) niche applications
→ "One-way" communication or sensing
→ Military and government systems

- Standard solutions preferable for …
  - Wireless LAN ("Ethernet Access")
  - Wireless PAN (SOHO)
  - "Smart home" wireless networking
  - Wireless web access ("Hot Spots")
  - *Ad hoc* communications between dissimilar devices (enterprise and/or home environment)
  - Combined data transfer and local positioning & tracking (LPT) for "location-aware" applications
  - Devices designed for "nomadic" communication and computing
  - Cable replacement (e.g., USB)

→ Commercial "mobile applications"
→ "Two-way" communication (with LPT)
→ "Plug-and-Play" devices and applications

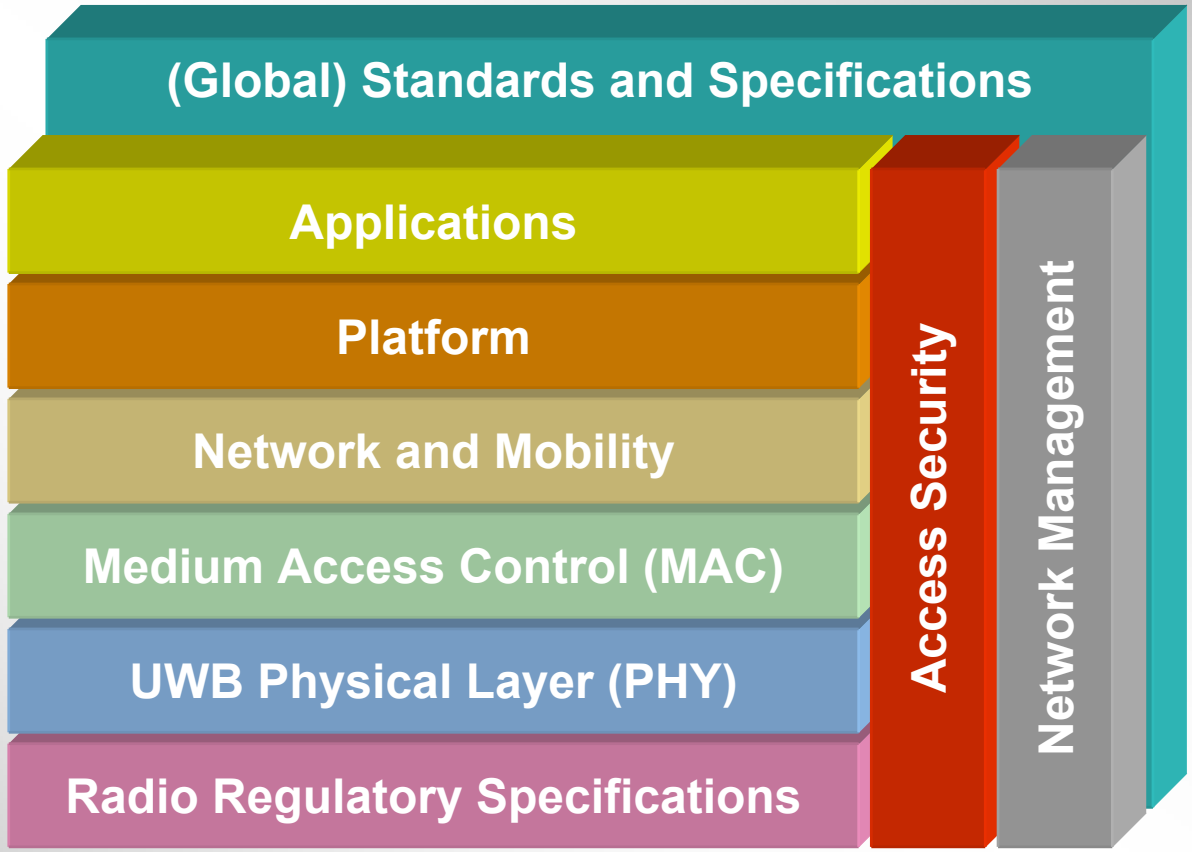
The View of a Wireless System Integrator

The Need for Standardized Devices and Applications

- Considering the wireless industry's efforts to foster increasing numbers of nomadic wireless users, global standards become ever more important for the long-term success of this industry.

- Without (global) standards and specifications at all levels of a wireless solution, chip and subsystem suppliers – as well as wireless system integrators – will not be able to supply the performance and high level of integration at the required low cost that would be possible with the much higher volumes feasible with such standards.

→ The UWB industry and the established members of the wireless industry should consider now to define their common interests and start efforts with the goal to achieve a (global) consensus on regulatory issues as well as standardization matters.



The View of a Wireless System Integrator

Some Interesting Applications – Local Positioning & Tracking (LPT)

- New Trend ››› Introduction of LPT functionality in existing WAN & PAN:
  - There is a growing need to support newly emerging "location-aware" applications,
  - Original user scenarios and WAN/PAN standards were defined without LPT in mind.

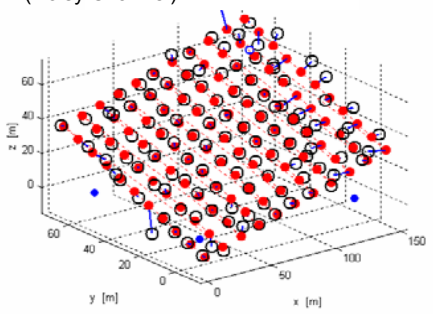
  → Achievable position accuracy is limited (e.g., bandwidth and/or range constraints).

- UWB Radio Technology ››› Ability to support data services and LPT functions:
  - UWB offers (precision) LPT as an inherent capability in (low-rate) data applications.

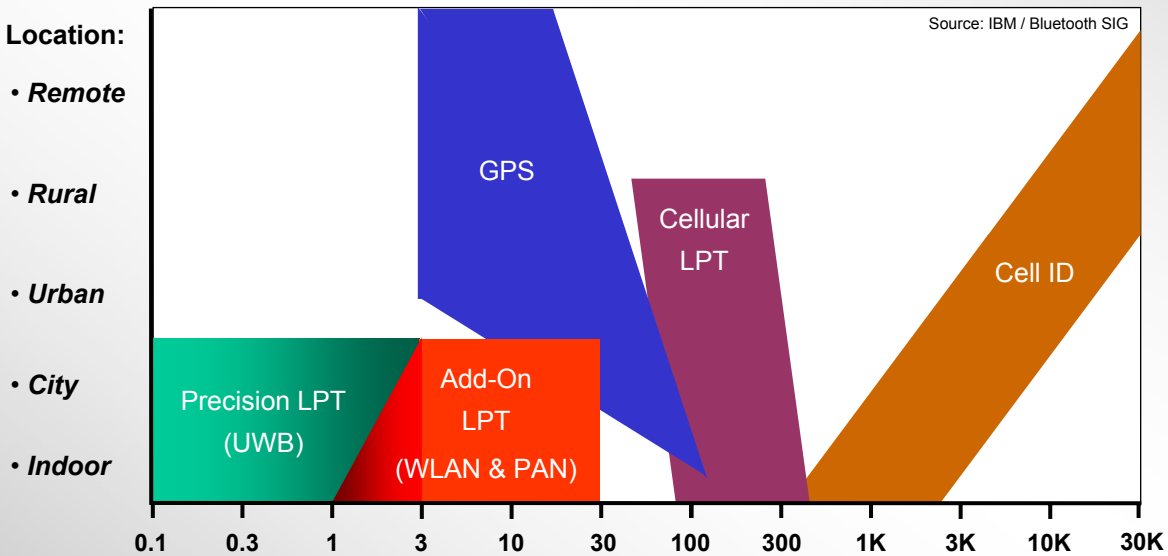
  → The emerging commercialization of UWB-RT is a unique opportunity to standardize UWB-PHY/MAC layers that **effectively** enable data- and location-based applications.

- 3D Positioning

Simulated Single Measurement
(Noisy Channel)



Source: IBM Zurich Research Laboratory



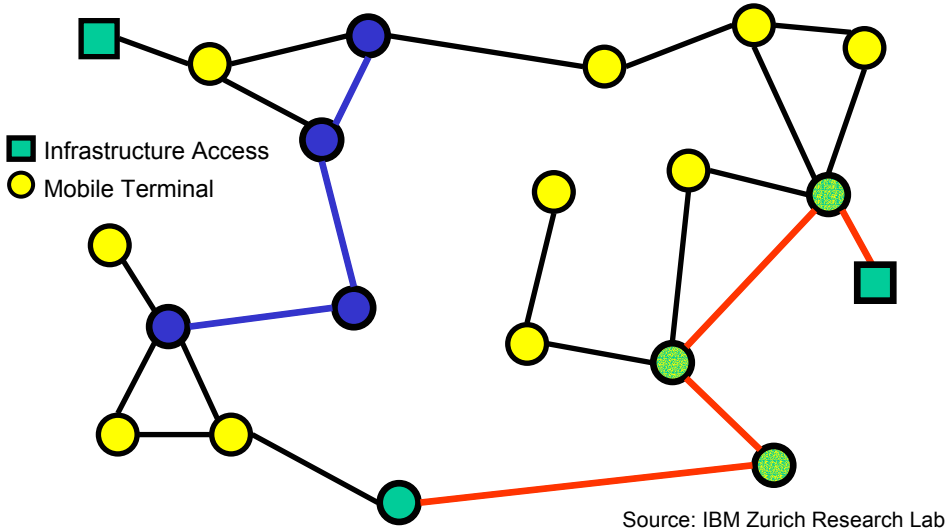
The View of a Wireless System Integrator

Applications – UWB Radio Enabling *ad hoc* Networking and Pervasive Computing

- "… while all these signal-processing algorithms promise much greater utilization of the radio spectrum, probably the most revolutionary concept is packet relay, in which each wireless device cooperatively forwards packets received from its neighbors toward their intended destinations …"
- "… such [*ad hoc*] networks scale to infinite [spatial] capacity – as the density of devices increases, each one lowers its transmitted power accordingly …" Robert W. Lucky, *IEEE Spectrum*, 9/2001

- Use location-based/multi-hop routing schemes based on incentive-driven participation of nodes.
- Home networking or pervasive computing - the Internet is being extended to everyday household appliances that we don't normally associate with computing:

  ››› Whether these devices will be connected wirelessly will much depend on performance and cost.



Source: IBM Zurich Research Lab


Source: IBM

Wireless World Research Forum (WWRF)

"A Global Platform to Design the Future of the Wireless World"

- On September 18, 2001, **Alcatel**, **Ericsson**, **Motorola**, **Nokia**, and **Siemens** announced the "Wireless World Research Forum (WWRF)" ››› http://www.wireless-world-research.org
- The WWRF is a non-profit organization under Swiss law.
- The forum so far counts over 40 corporate members representing world leading manufacturers, operators, and academic institutions.
- Work in 2001 was devoted to writing the Book of Visions 2001 (Version 1.0):
  - The Book of Visions describes visions, issues, and required research for the "Wireless World."
  - The term "Wireless World" covers wireless communications beyond the third generation (3G).
  - The Book of Visions serves as a basis for the preparation of coordinated research efforts and (international) research programs supported by the European Commission (EC).

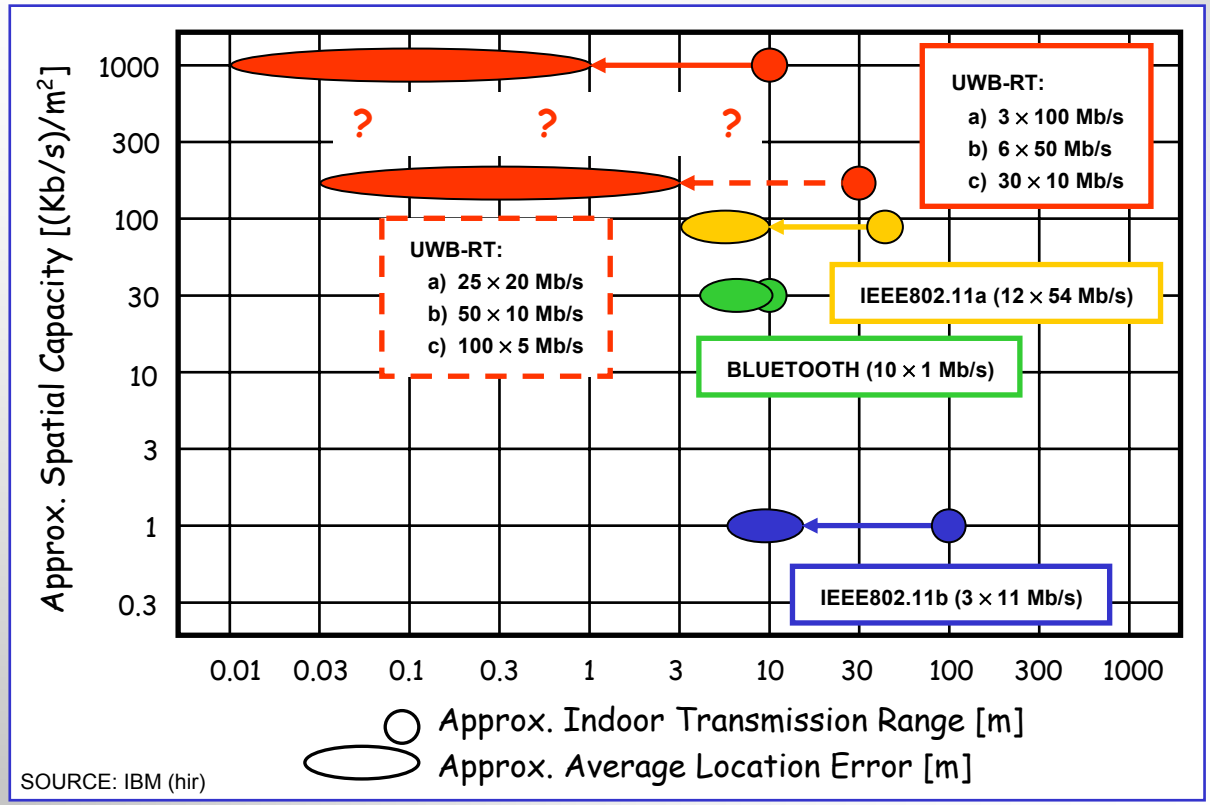
- The forum is establishing a research road-map that spans about 10 years to explore the future of the "Wireless World beyond 3G."
- The work program for 2002 will focus on system concepts and an agreed research agenda as a prerequisite for inclusion in research projects to be launched in 4Q2002 based on the EC's 6th Framework Program (http://www.europa.eu.int/comm/research).
- The forum will liaise with the UMTS Forum, ETSI, 3GPP, IETF, ITU, and other relevant bodies.

→ Researchers from academia and industrial organizations are invited to contribute to the forum.

The WWRF Initiative

UWB Radio Technology – "Book of Visions 2001 (Task 4.6)"

- **Objectives**
  - → PHY/MAC concepts for data and position location & tracking >>> Wireless PANs (>3G),
  - → Broad consensus on regulatory matters and consolidated submissions to standard bodies.



Conclusions (1)

- Is there sufficient technical evidence that UWB radio is useful and can work?
  - ✓ Basic technology issues have been studied and developed over many years.
  - ✓ Numerous studies, papers, and reports provide theoretical support for the claims of its benefits in the areas of communication, sensing, and positioning.
  - ✓ The pioneering UWB industry has developed and demonstrated a multitude of working prototypes, concept devices, as well as entire (field tested) systems and applications.
  - ✓ First-generation commercial devices (chips) and systems are presently being developed.
  - → Definitely **yes** … proof that the **basic PHY technology** works has been delivered, **but** …
  - → … many **system-level** and **operational issues** remain that need investigated or solved.

- What are the main criteria for integration of UWB devices in mobile platforms?
  - ? **Regulatory issues** must be resolved – preferably on a global scale ››› license-free use of UWB devices ››› commercially viable limits on system parameters (e.g., power, PRF).
  - ? **Standards** – preferably with global support – as well as clear definitions of user scenarios are prerequisites for widespread adoption and integration (e.g., IEEE P802.15.3-ALT PHY).
  - ? **Availability of** – or at least the prospect for – **convincing and differentiating applications** and solutions that can leverage the unique properties offered by UWB radio devices.
  - ? **Competitive** w.r.t cost, battery burden, performance, form factor, and EMC (host device).

- Wireless system integrators will adopt the technology if it provides them and their customers with real "value-add" → New applications should improve the "user experience (WWRF)."

Conclusions (2)