Bluetooth™ and 802.11 Compared

"No Bucks? No Buck Rogers!"

A famous scene in the Movie "The Right Stuff" showed the astronauts winning an argument with senior management and scientists about what *really* makes spacecraft fly. The managers and scientists protested that science and management was the reason. The winning answer from the astronauts was, "*Funding* makes these birds [missiles] fly, not science. No bucks? No Buck Rogers!"

To show you where the funding is flying between 802.11 and Bluetooth, a new study in July 2001 by Micrologic Research, "Wireless Data Communication 2001," forecasts that in 2005, *1.2 billion Bluetooth* chips and 25 million wireless LAN (WLAN) nodes will ship worldwide. In their March 2001 report on the WLAN market, the Cahners In-Stat Group predicts worldwide shipments of 802.11a/b/g nodes will be 22.7 million in 2005 to meet enterprise demands (including access points, PC cards, and embedded solutions). In contrast to 802.11, Cahners also states that devices with Bluetooth wireless technology will soar to 955 million units in 2005, a 360% five-year compound annual growth rate.

802.11 systems do not have this magnitude of cost reduction opportunity due to economies of scale. Bluetooth has a growing plethora of applications that are driving the production volumes of integrated chips up and their prices down. Bluetooth devices benefit from being true **digital duct tape** as shown in Table 2. Bluetooth is perfectly apposite for a wide range of uses that spans beyond desktop PCs, including consumer electronics, telecommunications, automotive, mobile computing, and entertainment. This ensures that Bluetooth wireless technology will always be cheaper than 802.11 systems.

"Just the facts, Ma'am."

The following table shows the general characteristics about Bluetooth and 802.11:

	◄ 2.4 GHz ►					5 GHz
	Bluetooth 1.1	**Bluetooth Medium Rate**	**Bluetooth High Rate**	**802.11b**	**802.11g**	**802.11a**
Application	General wireless	General wireless	General wireless	Wireless Ethernet for PC	Wireless Ethernet for PC	Wireless Ethernet for PC
Raw Bit Rate	1 Mbps	2 Mbps	10 Mbps	11 Mbps	36-54 Mbps	24-54 Mbps
Effective Bit Rate	500-700 kbps	1-1.5 Mbps	TBD	5-7 Mbps	TBD	TBD
Range	10-100 m	TBD	TBD	100-300 m	TBD	TBD
Available	Now	2003 est	2004 est	Now	2002 est	2002 est
Interference Resistance	High (1600 hops/sec)	High (1600 hops/sec)	High (TBD)	Reasonably High	Low	Low (Some mitigation of narrow-band interferers, OFDM with FEC)
IC Cost	$10-$15	$10-$15 est	TBD	$35-$45	$35-$45	TBD
Power	Low (1 to 35 mA)	Low (1 to 35 mA)	Medium TBD	High (100 to 350 mA)	High (100 to 350 mA)	Very high TBD
Footprint	Small (20 x 15 x 2 mm)	Small (15 x 15 x 2 mm)	Small TBD	Med (60 x 51 x 5 mm)	Large: TBD	Large: TBD

Table 1: Bluetooth and 802.11 General Characteristics

Bluetooth and 802.11 Are Complementary

There is no question (particularly if cost, size, and power are not the primary factors) about which technology to use for a wireless mobile network. 802.11 was designed for this.

Yet, it is important to realize that Bluetooth wireless communication devices are complementary with 802.11x WLANs. Designed as a cable-replacement technology and not intended as an 802.11 competitor, Bluetooth is not likely to eclipse 802.11 as the WLAN of choice. However, the Bluetooth product often has interesting and flexible features not found in 802.11 systems. This includes co-located separate (personal) networks, ad hoc networking, and synchronous channels that are particularly effective for voice applications and exceptionally low power operation for wireless link members. These connections can range from within group, point-to-point, point-to-multi-point (piconet and scatternet features), all of which can be accomplished automatically. Products with Bluetooth wireless technology are effective in an almost limitless number of applications beyond and including networking as shown in Figure 1 and Table 2.

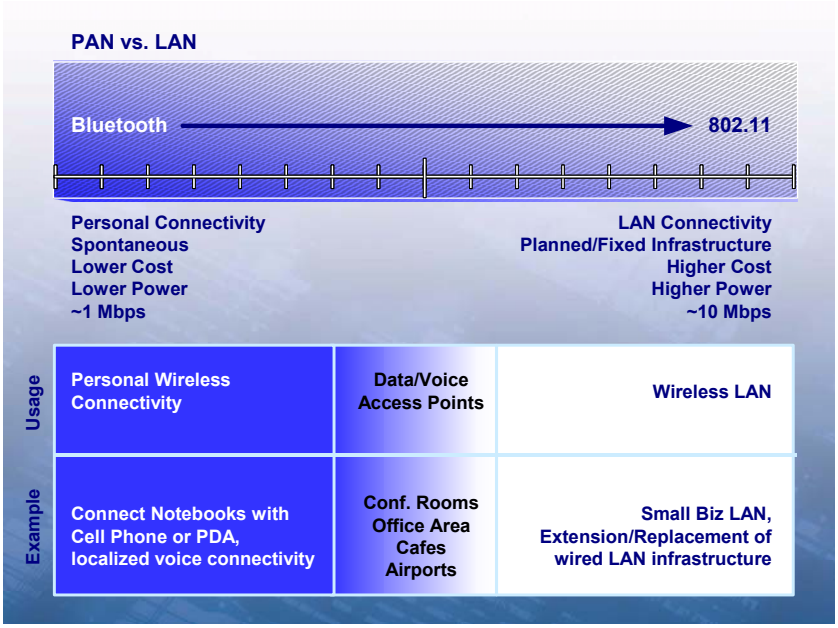

Figure 1: The Complimentary Continuum of Bluetooth and 802.11

Bluetooth has specializations for very low cost, low power applications with simple interfaces to printers especially useful for non-PC devices like cell phones and PDAs. Audio-video interfaces for use with consumer devices such as headsets, speakers, music players, remote controls and video conferencing are being added to the Bluetooth profiles.

The most common and complementary use for systems using both Bluetooth and 802.11 wireless technologies is mobile workers or business travelers that need Internet or intranet access. The notebook computer would use a Bluetooth link to a PCS mobile phone that would dial into an ISP for Internet and other network access.

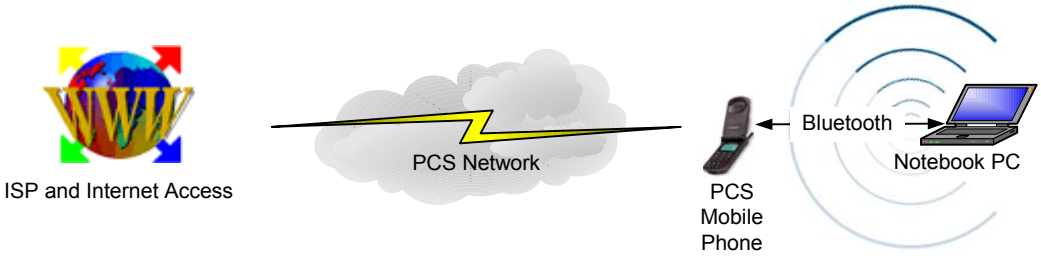

Figure 2: Mobile Use of Notebook with both Bluetooth and 802.11 Wireless Technologies

When within range, the same notebook could use its complimentary 802.11 capability to connect to the WLAN as shown in Figure 3. In addition to using this dual capability for corporate WLANs in the office, this technology is currently available in selected areas at Chicago's O'Hare International Airport. Vendors such as MobileStar are currently making this service available in San Jose and several major Hilton and Sheraton Hotels in cities such as New York, Phoenix, San Diego, and Boston. MobileStar claims it's in discussions with other airlines and hotel chains.

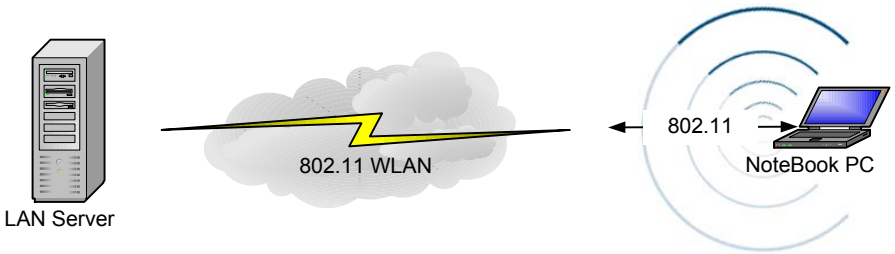

Figure 3: Fixed Use of Notebook with both Bluetooth and 802.11 Wireless Technologies

Another complimentary use of both 802.11 and Bluetooth technologies would be a person returning from a business trip wishing to synchronize new information on a PDA with a desktop PC. Bluetooth wireless technology permits this data transfer without the need for cables. Later, this information can be sent from the 802.11 equipped PC over the 802.11 WLAN to co-workers hundreds of meters away.

The 802.11 portion of this data transfer requires that the network administrator has already configured the PC and established network profiles and privileges. In contrast, the Bluetooth connection described above is created automatically and *without assistance* from IT/IS departments or network services typically associated with most LANs (WLANs as well as hard-wired networks). This ad hoc network is commonly referred to as a wireless personal area network (WPAN).

Bluetooth WPANs can consist of just two units (a master and a slave), 8 units (a master and seven slaves), called a "piconet," or two or more interconnected piconets, called a "scatternet." Granted, this limited networking is not a WLAN nor can existing 802.11 WLANs offer such flexibility. Nevertheless, Bluetooth can be a "bridge" to a WLAN. Fully endorsing this "bridge" idea, wireless service providers fully expect their cellular networks to be used by gadget gurus and wireless warriors to connect Bluetooth equipped devices to the Internet, corporate LANs, and wireless data networks.

Simultaneous versus Staggered Use of Bluetooth and 802.11

Recent reviews of products that feature 802.11 and Bluetooth technologies on the same device have discovered throughput reductions if both technologies are used simultaneously. Accordingly, most first generation wireless devices that offer both technologies are expected to use these RF protocols separately or in a staggered fashion.

Size Matters

Bluetooth technology has successfully achieved very small form factors in comparison to its 802.11 counterparts. The first generation Bluetooth systems range from about 32-by-17-by-2 mm to 20-by-15-by-2 mm. Second generation Bluetooth systems are expected to be approximately 15-by-15-by-2 mm and many vendors are squeezing the footprint much smaller.

Typical 802.11 systems use PC cards with significantly larger footprints and much higher power requirements. With current 802.11b Mini-PCI reference designs measuring 60-by-51-by-5 mm and consuming much more power than Bluetooth technology, it is unlikely that cell phones will be equipped with 802.11 technology in the near future.

Bluetooth is Lower Power

Bluetooth is intended for portable products, short ranges, and limited battery power. As a result, it offers exceptionally low power consumption and, in some cases, will not measurably effect battery life. On the other hand, 802.11 is designed for longer range transmission (up to 300 meters) and, by definition, must consume *significantly* more power.

On average, a typical Bluetooth device uses from about 1 to 35 mA while an 802.11 system requires between 10 and 100 times more juice at anything from 100 to 350 mA. Not surprisingly, this dramatic difference in power consumption is why Bluetooth is the only practical choice for mobile applications with limited battery power. On the other hand, when greater range is needed and there are plenty of wall sockets within reach, 802.11 is the ideal solution.

What About Costs?

From its inception, Bluetooth has been designed to achieve a total BOM of $5 by 2005. Three factors will drive the cost of Bluetooth to $5 by 2005.

1. Digital integration: Bluetooth baseband functionality will integrate into a small 40k-gate footprint on host processors. Mobile phone manufacturers have announced plans to integrate the Bluetooth digital functionality into handset baseband chips, and numerous IP licensing announcements have been made by Silicon Wave, Parthus, Ericsson, Newlogic, and Tality. More specifically, Qualcomm has already taken the step of offering Bluetooth functionality in its CDMA baseband chip, the MSM5100. As a result, a sub-$5 radio becomes the only cost adder.
2. Competition: a multitude of semiconductor and software companies are competing for a share of this 1 billion-unit market in 2005. The ARC Group's 2001 Bluetooth Survey revealed that 25 semiconductor companies are providing Bluetooth IP or IC's, 60 companies are prepared to launch application products, and over 250 Bluetooth products are available on the market today.
3. Sheer volume: high volume delivers lower cost. By most analysts' forecasts, Bluetooth will be about a 1 billion-unit market by 2005. Expect to see Bluetooth unit sales grow at least 350% in 2002. Some analysts predict several times this growth.

In contrast, 802.11 remains relatively high-cost (for enterprises, access points cost between $500 and $1,000 and network interface cards range from $100 to $200). In addition, shipments of 25 million WLAN nodes by 2005 pales in comparison to Bluetooth's cool billion. However, if range and throughput is more important than size and cost, then 802.11 is a clear winner over Bluetooth. With the exception, that is, of spatial capacity in a densely packed RF environment.

Spatial Capacity

802.11 systems are limited by specification to three co-located systems, while the Bluetooth specification permits up to ten co-located systems. This results in better spatial capacity for the 10-system Bluetooth network than for the 3-system 802.11 network. The difference in spatial capacity for the two systems is shown in Figure 4.

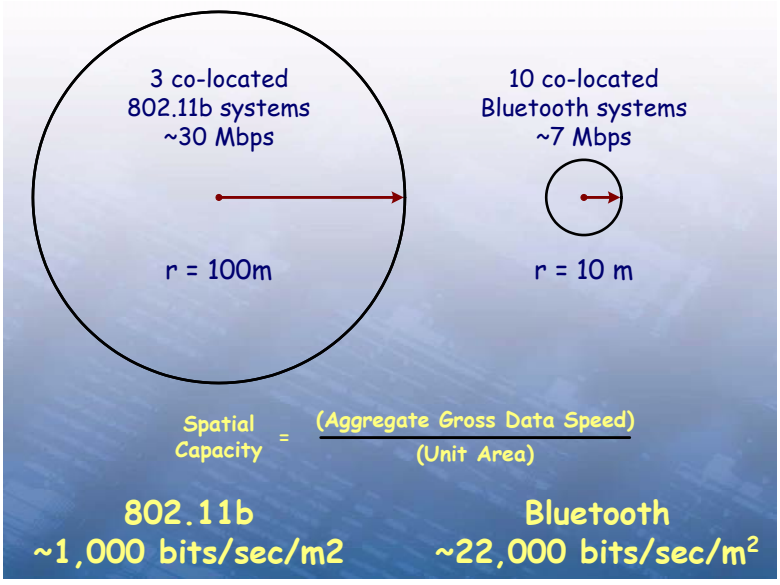

Figure 4: Spatial Capacity

Interference between 802.11 and Bluetooth

There has been a lot of discussion on interference between the two radio technologies. Interference will occur, but the two technologies are designed to tolerate it. However, this issue will be important when more devices are available supporting the two technologies. In the future, more or less all devices will have a wireless connection and the Bluetooth SIG and Wireless LAN standardization committees have identified this "problem." The 802.15 Coexistence Task Group 2 and the Bluetooth SIG Coexistence Working Group are addressing this matter with the objective to minimize the "problem" even more by making the 802.11 and Bluetooth standards benignly coexist. An example is the proposed "adaptive frequency-hopping scheme" in Bluetooth. This would permit Bluetooth radios to identify and avoid those channels (frequencies) in use by 802.11 systems and increase throughput while minimizing (or eliminating) interference for *both* systems. The FCC has been asked to change the rules in Part 15 to permit Bluetooth units to adaptively select a subset of the ISM band frequencies over which to perform the frequency hopping required of such devices. The FCC is currently considering the recommendations of the industry.

Dynamic Technology

Last year the Bluetooth Special Interest Group (SIG) tasked its Radio-2 committee to deliver an enhanced version of the Bluetooth specification that includes a 2 and a 10 Mbps version as well as the ability to recognize Bluetooth devices more quickly. These faster data rates would be significant for hand held devices that demand little or no effect on battery life. Examples would be cell phones, PDAs, and palm/notebook devices, particularly for 3G systems that employ advanced audio and video technology.

802.11 systems are undergoing similar development with increasing interest in the 802.11a specification that uses the 5 GHz band instead of the 2.4 GHz ISM band for Bluetooth and 802.11g extensions to the currently deployed 802.11b wireless technologies. The 802.11 committees are also attempting to define a quality of service design to facilitate better sharing of the capacity of a given radio channel and also to bring 802.11 closer to being able to deliver a satisfactory user experience with real-time data applications.

In short, understanding where Bluetooth and 802.11 technologies are today, or yesterday, almost assures misunderstanding them tomorrow unless you stay informed about their continuous and complimentary development.

Summary: Key Points and Review

802.11 and Bluetooth are complimentary. Some products will have *both* technologies this year. (For example, samples of both the TRD and TRA TrueRadio chips from Mobilian will be available in late 2001 with production quantities to follow as part of future customer announcements.)

802.11 is the WLAN of choice where range and throughput are more important than size and cost. Bluetooth is preferred where size, cost, and mobility are more important than range and throughput.

802.11b costs more than Bluetooth: 802.11b chipsets are 4 times the cost of Bluetooth solutions today. For mobile phones, the cost is 8x.

802.11b consumes more battery life: 802.11b is approximately 10x more power consumption or 10x less battery life (350 mA versus 35 mA).

802.11b is too big for most mobile applications: 802.11b Mini-PCI reference designs are 60 x 51 x 5 mm. Bluetooth is 20 x 15 x 2 mm and rapidly diminishing in size. 802.11b consumes 21 times more space than the first generation BT solutions. 802.11 is currently a 5-chip solution that is moving toward a 2-chip solution. Bluetooth is a two-chip solution moving toward a single-chip solution.

802.11b does not offer voice solutions.

The IEEE has formed the 802.15 Coexistence Task Group 2 to improve coexistence among PANs in the 2.4 GHz frequency spectrum. Similarly, the Bluetooth SIG has formed a coexistence working group to improve the simultaneous operation of 2.4 GHz ISM devices.

The key word for Bluetooth is mobile. While Bluetooth can be used in almost unlimited applications, its strongest benefit is for mobile workers and business travelers by permitting a notebook PC to connect to any wireless network (inter as well as intranets) via a cellular telephone.

The key words for 802.11 are range and throughput. It is the WLAN of choice where these features are needed more than low cost, small size, efficient battery use, and mobility.

Finally, both 802.11 and Bluetooth will continue refinement.

802.11 and Bluetooth Compared

802.11	Bluetooth
Optimized for: Home/campus/office WLAN.	**Optimized for:** Cable replacement with limited wireless network capability.
Range: 15–150 meters indoors and 300 meters outdoors.	**Range:** 10-meter range, 100-meter range with higher transmit power.
Data rate: Faster data rate: **802.11a**: 24 to 54 Mbps. 5 GHz band. Actual raw rate is comparable to a common Ethernet without switch devices. In actual use, the net speed of the solution is estimated to be about 40% of this, which is roughly 10 to 22 Mbps. May not be available outside the US due to band allocation problems. **802.11b**: 2.4-GHz ISM band. 11 Mbps raw data rate (may double). **802.11g**: Extends existing 802.11b to 36–54 Mbps with full backwards compatibility.	**Data rate:** Slower data rate: 1 Mbps raw data rate (2FSK) An asymmetric data rate of 723 Kbps (while permitting 57 kbps in return direction) and symmetric rate of 432.6 kbps is possible according to Bluetooth specifications. A future version of the Bluetooth specification is expected to elevate the data rate to 2 Mbps. A later version will provide approx. 10 Mbps.
Frequency: **802.11a**: 5 GHz OFDM in 20 MHz channels (Orthogonal Frequency-Division Multiplexing). **802.11 b**: 2.4 GHz, fixed 11 MHz channel (DSSS). **802.11g**: 2.4 GHz, fixed 11 MHz channel (OFDM).	**Frequency:** 2.4 GHz, 1600 hops/sec radio (FHSS) 1 MHz channels over 79 MHz.
Hostile RF environment tolerance: DSSS (.11b) and OFDM modulation (.11g and a) provide interference mitigation. Longer, less noise resistant packets. Less likely to tolerate hostile RF environment with noise, interference, & channel collisions.	**Hostile RF environment tolerance:** FHSS helps Bluetooth evade interference and withstand noise that could swamp IEEE 802.11. Shorter, more noise resistant packets. ARQ (Automatic Repeat request). 16-bit CRC (cyclical redundancy check).
Size: Larger footprint/PC Card. Most systems that include baseband, radio, integrated IP on host & core logic are 5 ICs moving toward 3 ICs. See Table 1 for typical dimensions.	**Size:** Very highly integrated, smaller footprint. Most systems that include baseband, radio, integrated IP on host & core logic are 2 ICs moving toward a single IC. See Table 1 for typical dimensions.
Cost: (High volume) Higher. (Average chip set price =$35 to $40 this year).	**Cost: (High volume)** Lower. (Average chip set price = < $10 this year, < $6.50 in 2002, and < $5 in 2003).
Current consumption: Higher current draw, shorter battery life for handheld/portable devices. Averages about 10x the power consumption of Bluetooth. Does not have as sophisticated power saving protocols.	**Current consumption:** Lower current draw, especially in low power modes, longer/unaffected battery life. Averages about 1 to 35 mA.

Network options: No pico or scatternets. Effective at random access.	**Network options:** Ad hoc in nature. Piconets with several devices can be made, scatternet possible. Works best with known or regular access that can be controlled by the master of the piconet.
Co-existence with Bluetooth: May interfere if they are active in the same area. 802.15 Working Group is developing co-existence methods between 802.11 and Bluetooth wireless technology. Longer packets may be more susceptible to collisions, require more frequent re-transmissions, and adversely affect throughput in high traffic environments. 802.11 products need to enhance their fallback algorithms so that they do not exacerbate the interference phenomenon by inappropriately lengthening their data packets when they encounter interference from Bluetooth radios.	**Co-existence with 802.11b:** May interfere if they are active in the same area. 802.15 Working Group is developing co-existence methods between 802.11 and Bluetooth wireless technology. Shorter packets and randomly selected frequencies may be less susceptible to collisions, require fewer re-transmissions, and experience less reduction of throughput in high activity environments. See: Mobilian, Silicon Wave, Intersil, CSR (dual mode).
Security: 40-bit RC4 or optional WEP (Wired Equivalent Policy) 64-bit and 128 bit encryption capability. International regulations may conflict with higher security levels.	**Security:** Effective key length of the algorithm is selectable between 8 or 128 bits. Thus, Bluetooth can be used in countries with regulations limiting encryption strength.
Popular applications: Desktop PCs/Notebook PCs/Wireless LANs. Apple Airport. High-end palmtops.	**Popular applications:** Palmtops. Notebook PCs. Printers. Cellular telephones.
General: Corporate wireless networks (LANs). Limited/expensive applications. Primarily desktop PCs/notebook PCs.	**General: "Digital duct tape."** Can be used to do numerous tasks: • Replace cables for keyboards, mice, PDAs, cell phones, headsets, PDAs, notebook PCs, personal stereos (CD/MP3), speakers. • Establish a PAN without technical assistance. • Network access points. • Send/receive email. • Make reservations. • Print/fax documents from cell phones or PDAs; synchronize PDAs with PCs. • Send data to multiple devices simultaneously. • Wireless, multiplayer games. • Automotive systems–arm/disarm security systems, perform remote diagnostics, etc. • Industrial/control systems. • Medical systems–allows instant access to critical patient information (BT ID bracelet transmits blood type, allergies, and other "need-to-know" information to medical personnel even if patient is unconscious). • Transaction oriented processes.

	• Wireless link for “electronic wallet.” • Purchase consumer items without human interaction (e.g. drive-through gas pumps, car washes, toll booths, fast food restaurants, etc.). • Friend "seeker" (locate other people). • Information kiosk. • Promises to "end lines, queues, waiting…" • Travel/directions guide (airports, stores – could be built-in to shopping carts, lounge seats, etc.). • Remote entry (arm/disarm security systems in home/office).

Table 2: 802.11 and Bluetooth Compared

Key Bluetooth Features

- **Longer Battery Life.**
- **Robust Encryption** (128 bit).
- **Voice** (CVSD proven resistant to high interference environments).
- **Simultaneous Voice and Data Modes**: Commil Technology (Petah Tikva, Israel, 972-3-9217770).
  - 432 Kbps (full duplex).
  - 723 Kbps / 55 Kbps (asymmetric).
  - 3 simultaneous full duplex voice per piconet (CVSD @ 64 Kbps).
- **Mobility** – Bluetooth is highly integrated into very small, lightweight products.
- **Networking** (ad hoc) flexible options:
  - Within group.
  - Point-to-point.
  - Point-to-multi-point (piconet).
  - Scatternet.
- **Digital Duct Tape**. Bluetooth has an exceptionally flexible architecture. This allows a multitude of applications (see Table 2, above). Version 1.1 of the Bluetooth specification defines 13 profiles:
  1. Generic Access Profile.
  2. Service Discovery Application Profile.
  3. Cordless Telephone Profile.
  4. Intercom Profile.
  5. Serial Port Profile.
  6. Headset Profile.
  7. Dial-up Networking Profile.
  8. Fax Profile.
  9. WLAN Access Profile.
  10. Generic Object Exchange Profile.
  11. Object Push Profile.
  12. File Transfer Profile.
  13. Synchronization Profile.

  The following profiles are in development:
  1. Personal Area Network (PAN) Profile.
  2. Printing Profiles.
  3. Digital Image Transfer Profile.
  4. Local Positioning – transferring location coordinates and assisting the determination of position.
  5. Advanced Audio-Video Profiles.
  6. Automotive Profiles.
  7. ISDN Profile.

- **Spatial Capacity Comparison** (see Figure 4):
  - 10 co-located **BT** systems = approx 10 Mbps.
    Radius of 10 meters = approx **30, 000 bits/sec/m²**.
  - 3 co-located **802.11b** systems = approx 33 Mbps.
    Radius of 100 meters = approx **1,000 bits/sec/m²**.

Table 3: Key Bluetooth Features

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