

How will it PAN out?

Bluetooth 3.0 High-Speed versus Wi-Fi Direct

Neil Tebbutt, John Prince, Pietro Capretta

28th May 2010

Abstract

Bluetooth 3.0 High-Speed and Wi-Fi Direct are competing for high-speed data transfer in Wireless Personal Area Networks (WPAN's). This article analyzes the technical and business tradeoffs between these two emerging technologies and their deployment in the coming years. With the trends to smaller, slicker cellular phones with fewer antenna's, Wi-Fi Direct is poised to capture the high-speed data transmission segment in WPAN and will eventually replace Bluetooth for voice and audio transmission. Bluetooth will move towards low data rate low energy transfers with sensors.

1 Introduction

Bill uses his laptop PC to purchase the latest album from his favorite online music store. He listens to a few tracks by streaming the music to his home stereo using a fast wireless link, and uses the same wireless link to download the album to his smartphone. Jane arrives at the house with some photos she took on her smartphone. Using a fast wireless link she zaps them onto the HD-TV set to show Bill. Ben arrives with a video clip on his digital camera and streams this to Ben's TV over the same wireless link. He also uploads a copy of Jane's photos from her smartphone to his camera using a fast wireless link. When he gets home he prints a set of Jane's photos on his printer using a fast wireless link to his camera. During all of these operations, over 200MB of data was exchanged in a few seconds without the use of a single cable and without using a cellular wireless network.

Sounds like something from "Star Trek"? Not anymore! Two technologies are vying to provide the "fast wireless link" that links devices in an ad-hoc, peer-to-peer manner; Bluetooth 3.0 High-Speed and the newly-announced Wi-Fi Direct. Both technologies would make such ad-hoc, peer-to-peer communication easier and real over existing standards. The big question is which will prevail and where should we make our bets for the future?

2 Overview of Bluetooth High-Speed

Lifetime shipments of Bluetooth devices are currently approaching 3 billion units, with around 1Bu shipped in 2008 and slightly less in 2009. Bluetooth's installed base is dominated by mobile phones, where the overall attach rate is around 70% (and rising), and is near 100% in the Feature Phone and Smart Phone segments. The key use cases are voice and music streaming to headsets and car-kits, and small object transfer (e.g. business cards, phone book, single photos, small files). There is a paradox in that despite the huge number of BT devices shipped, only around 12-15% of them are ever actually used (12-15% is the percentage of headsets and car-kits shipped compared to BT-enabled devices shipped). There is a wide variety of other Bluetooth devices and applications (e.g. BT mouse, keyboard, games controllers, etc), but the numbers shipped are small compared to Bluetooth in mobile phones.

Bluetooth wireless technology was designed from the beginning to provide a cheap, low – power, peer-to-peer, ad-hoc wireless link, thus eliminating signal wires between devices. However, the classical Bluetooth radio is incapable of high speed operation (approx 2 Mbs maximum), thus making the transfer of large multimedia files uncomfortably slow.

The Bluetooth 3.0 High-Speed specification uses a second radio as a “turbo-channel” which the Bluetooth protocol uses to send bursts of data at high speed before reverting to the classic Bluetooth radio to save power. The 802.11 radio was selected, since it is mature, it provides the required throughput, and it is available more and more frequently within the Bluetooth installed base.

The secondary radio is called an AMP (Alternate MAC/PHY) and the Bluetooth specification provides for the creation of several different AMP's. The first (and so far, only) AMP to be implemented is based on the IEEE 802.11a/b/g specification, and a minor upgrade to include 802.11n is planned for 2010. In the past, UWB technology was also intended for use as an AMP, but with the demise of UWB, this has been abandoned by the SIG. One of the 60 GHz radio variants is a potential future AMP candidate.

The AMP radio is entirely under the control of the classic Bluetooth radio. Once a Bluetooth link has been set up between devices, they interrogate each other to determine the presence (or not) of an 802.11 AMP. If this is supported on both devices, then Bluetooth will automatically set up the AMP link, use it when required, and take it down again afterwards to save power.

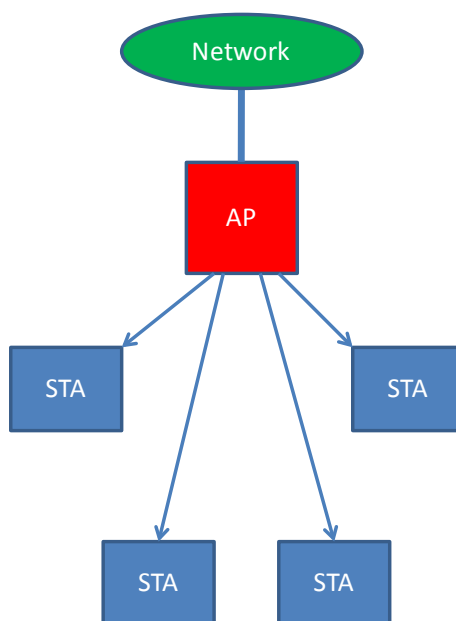
The presence of an AMP is largely invisible to both users and applications developers. Users see file transfers and synchronization activities running 10X faster (around 25Mbps maximum throughput), and applications developers use the same profiles as for classic Bluetooth. The look and feel of Bluetooth is the same as before.

Of course, this is a 2-radio system, and both radios must be present at each end of the wireless pipe. Although hardware modifications are not necessary on the two radio chips, additions and changes are required for the protocol stacks.

3 Overview of Wi-Fi Direct

Lifetime shipments of Wi-Fi products are currently about 2 Billion units, with 387Mu shipped in 2008 and more than 475Mu shipped in 2009. Wi-Fi's installed base is dominated by PC's, where the attach rate is 100% for laptops and portable PC's (desktop PC's tend to use Ethernet wired network connectivity). The key use cases are wireless internet and wireless networking operations, and these are expanding into the home/consumer environment. Wi-Fi Direct is derived from Intel's "Cliffside" development for P2P Wi-Fi, and has a lot of industry heavyweights behind it (Intel, Dell, Microsoft, Apple, HP, etc).

Classic Wi-Fi is a wireless networking technology. Unlike Bluetooth, Wi-Fi is not peer-to-peer, but is a star architecture, consisting of several terminals (STA's) connected to an Access Point (AP), which in turn acts as a bridge to the Network. This is shown in the diagram below.

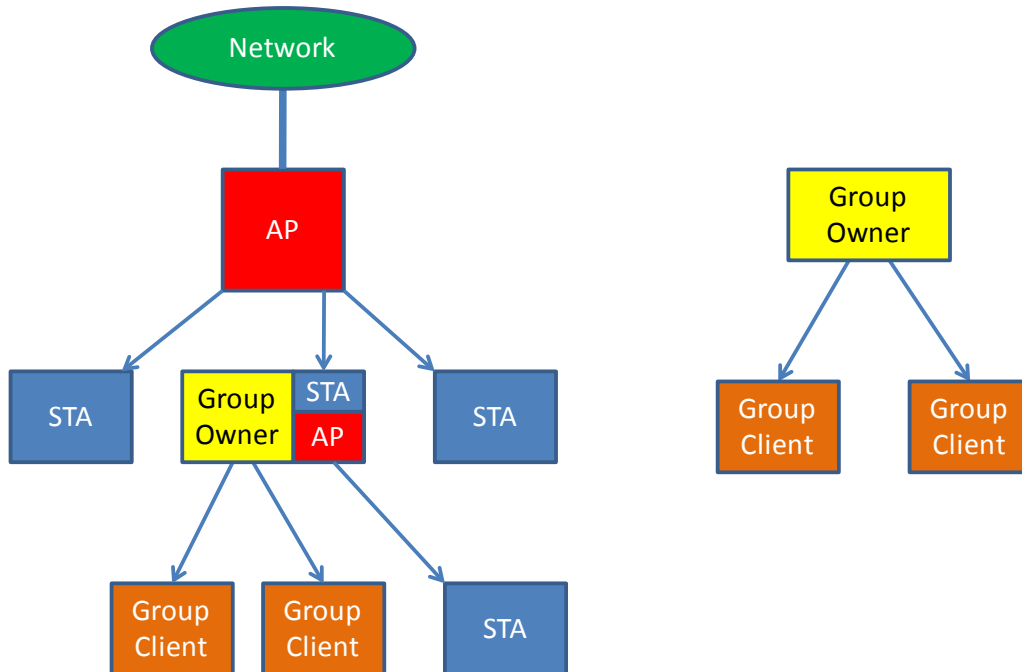


Wi-Fi theoretically supports ad-hoc, peer-to-peer communication between STA's. Several methods exist, two of which are as follows.

- It is possible to setup an independent network (IBSS) with direct STA to STA mode of operation that does not rely on the AP of an infrastructure network (BSS).
- It is possible for one STA to send packets to another STA via the common AP that controls both of them, thus imitating a "Peer-to-peer" mode by means of 2 hop packet routing.

These ad-hoc modes have never been widely used because of the lack of a standardized MAC protocol to forward packets across the ad-hoc WLAN network to access the Internet, and because of the difficulty for consumers to configure their computers even for the simplest ad-hoc peer-to-peer network in the presence of an Enterprise networking environment. However, they do exist and (for example) the Apple Apps Store contains an App that allows an iPhone to communicate with a Mac PC (or another iPhone) via a home Wi-Fi network.

Wi-Fi Direct is a new development from the Wi-Fi Alliance, aimed at providing a true peer-to-peer connection between Wi-Fi devices. It works by extending the existing Access Point (AP) and STA client-server architecture with the introduction of two new devices; a Group Owner (GO), and a Group Client (GC) which can connect in an ad-hoc, peer-to-peer manner. A **Group Owner** is a server device that can set up multiple peer-to-peer links with Group Clients. The same device can optionally be configured to operate simultaneously as an STA and as an AP in a classical Wi-Fi network. A **Group Client** operates similar to an STA with the additional capability to connect peer-to-peer with a Group Owner. This is shown in the diagrams below.



The AP/STA/GO/GC architecture offers a flexible combination of classic Wi-Fi and Wi-Fi Direct activities. For example, multiple peripheral devices (GC's) may be connected P2P to a personal computer (GO) using Wi-Fi Direct, which in turn is connected to the corporate or home network using a classic Wi-Fi Access Point (left diagram above). The GO provides the bridge from the ad-hoc network to the classic Enterprise network's AP. However, the GO is not required to furnish this forwarding service, and may simply be used for peer-to-peer communications between devices outside of a formal network (right diagram above).

The new GO and GC devices integrate seamlessly with the considerable existing base of legacy Wi-Fi equipment. Although peer-to-peer operation requires a GO/GC pair at each end of a link, an STA can connect to a Group Owner via a legacy (non-P2P) Wi-Fi connection (in which case the GO appears to the STA as a classical Wi-Fi AP).

In addition to the Group Owner/Client functions, Wi-Fi Direct also specifies a Power Saving feature in order to make it suitable for battery-powered devices. This basically allows GO's and GC's to schedule periods of "standby mode", where the radio is not active.

Wi-Fi Direct uses an existing 802.11 radio and is therefore a single radio system, unlike Bluetooth 3.0+HS. New MAC firmware is required to implement the Group Owner/Client and Power Saving features on existing Wi-Fi Certified devices, but since most devices have "soft" MAC's (downloadable into RAM), this is a straightforward upgrade.

4 Comparison of Bluetooth HS versus Wi-Fi Direct

4.1 Throughput

Both Bluetooth 3.0+HS and Wi-Fi Direct use the IEEE 802.11a/b/g/n radio as the high-speed transfer medium and consequently both technologies offer the same PHY data rates. Slight differences in throughput at the application layer would be due to efficiencies of the MAC and in the rate adaptation algorithms that select the optimal PHY features for channel conditions. The stated objective of Bluetooth 3.0+HS is 25Mbps minimum, delivered to the application under conditions of no-contention with other ISM band radios. Wi-Fi Direct performance at the application level is expected to be similar.

4.2 Range

The range of Bluetooth 3.0+HS is the same as classic Bluetooth (normally around 10m), although long-range (several 100's of meters) versions can easily be implemented with good antenna design and increased power output. The 802.11 AMP radio has a longer intrinsic range, but the high-speed link is dropped if the classic Bluetooth link is broken.

The Wi-Fi Direct link has a similar range to normal Wi-Fi operations; approximately 100m.

For most use cases from a personal area network perspective, a range of 10m is quite adequate.

4.3 Power consumption

In active mode, Bluetooth 3.0+HS and Wi-Fi Direct both use an 802.11a/b/g/n radio to transfer data. Therefore it is expected that the active mode power consumption will be equivalent.

In standby mode, Bluetooth 3.0+HS completely disables the 802.11 radio and uses Bluetooth to maintain a low-power link. This provides a very low power standby mode.

“Power Saving Mode” for Wi-Fi Direct is not completely defined, so it is difficult to make an accurate comparison. Due to the desire to not change any hardware, it is likely that Wi-Fi Direct will exploit the same (100ms) timer that the Enterprise networks implement for going in and out of standby mode to conserve power. It should be noted that low-power Wi-Fi chips intended for use in low-speed peripherals (e.g. mouse, keyboard, audio headset) have been announced.

The nature of the 802.11 radio versus a Bluetooth radio makes it a near certainty that Bluetooth 3.0+HS will consume less energy in standby mode, but it is currently unclear what the actual difference between the two technologies will be.

4.4 Schedule

Bluetooth 3.0+HS was released in April 2009.

Wi-Fi Direct spec development started in June 2008 and is expected to be completed during 3rd quarter 2010.

On paper, Bluetooth 3.0+HS has an 18 month lead over Wi-Fi Direct in terms of specification availability. However, the true situation is a little different. The specification that was released in April 2009 concerned only the AMP and PAL features which are the basis of the dual-radio high-speed link. But in order to reach the full throughput potential of the AMP and PAL, a bottleneck in the Bluetooth Host protocol stack needs to be removed (L2CAP, OBEX and Profile enhancements). This is currently being done, and is scheduled for release in Q2 2010.

Despite support for Bluetooth 3.0+HS from several chip-makers and protocol stack suppliers, the technology has not appeared in any end-products so far. Mobile Phone OEM's are showing no detectable move to implement Bluetooth 3.0+HS in new handsets or platforms. This might be indicative of their skepticism of high-speed, P2P content transfer as a killer use case (or operators' abhorrence of this feature). Or they may be waiting for the completion of the L2CAP/OBEX Host stack and Profile changes referred to above. It is also possible that the announcement of Wi-Fi Direct, and the rise of Smartphones (all of which support Wi-Fi), have sparked a "wait and see" attitude. Finally, it is clear that Bluetooth Low Energy (BT 4.0) is currently of more interest at mobile phone OEM's and development resources have been prioritized in this direction.

PC OEM's are clearly waiting for Wi-Fi Direct, and this is expected since many of them are key driving forces behind this technology. Since the attach rate of standard Wi-Fi into laptops is 100%, it is natural that PC manufacturers will plan on upgrading this when Wi-Fi Direct is released, rather than switching to Bluetooth 3.0+HS now. A pre-standards based version of Wi-Fi Direct is shipping as in Windows 7 and a software update is expected to provide a fully interoperable version when Wi-Fi Alliance Certification becomes available. Windows 7 contains a Bluetooth stack, but not BT3.0+HS.

4.5 Hardware

Neither Bluetooth 3.0+HS nor Wi-Fi Direct require hardware changes in either the Bluetooth Controller IC or the WLAN IC. The high-speed P2P link is implemented purely in software.

Wi-Fi Direct requires a single 802.11 radio, which can be shared with standard Wi-Fi activities. An existing, legacy Wi-Fi device can connect to a Wi-Fi Direct enabled device.

Bluetooth 3.0+HS requires two radios: Bluetooth and 802.11a/b/g/n. This is clearly a handicap for adding a BT-HS to equipment that has neither Bluetooth nor an 802.11 radio. However, it is expected that the major target areas for Bluetooth 3.0+HS are in equipment that already has both Bluetooth and Wi-Fi; for example, smartphones, laptop and netbook PC's.

4.6 Software

Bluetooth 3.0+HS requires new software in two areas

- On the Bluetooth Host controller, to implement the AMP (Alternate MAC/PHY) high speed channel and interface it to standard Bluetooth operation. This must be

implemented by the OEM (if an in-house host stack is used) or by the host stack supplier.

- On the 802.11 device, to implement a PAL (Protocol Adaption Layer) to translate between the Bluetooth and 802.11 protocol and data/frame structure, plus an HCI (Host Command Interface) for control purposes. These will normally be implemented and certified by the Wi-Fi chip supplier.

The Wi-Fi Direct specification is under final definition, but the general principles are stable. As described earlier, the basic features to be implemented are Group Owner/Client and Power Saving. These will normally be implemented by the Wi-Fi chip supplier. Most WLAN chips implement a “soft MAC” whereby the MAC firmware is downloaded by the Host. This will allow a rapid and flexible rollout of the new software required by WiFi Direct.

The above descriptions cover the lower layer protocol stack functionality. For the upper stack layers and the application software, both contained in the Host device, there are major differences between Bluetooth and Wi-Fi Direct.

For Bluetooth 3.0+HS, very little (if anything) needs to be changed. As has been noted previously, an upgrade to the Host protocol stack and some profiles is required to take full advantage of the HS channel, but most of the Bluetooth system will simply run faster over the 802.11 link as compared to running over the Bluetooth link. Most importantly, all of the link set-up, authentication, pairing, encryption and service discovery remain exactly the same. Basically, the “look and feel” of classical Bluetooth is preserved.

The situation will be quite different for WiFi Direct. Standard Wi-Fi is a WLAN technology and is not a natural peer-to-peer WPAN technology. Wi-Fi Direct will need to implement a complete, new sub-system for easily and securely establishing and removing ad-hoc links, plus service discovery. It will attempt to leverage proven mechanisms for pairing Group Owners with Group Clients. Any remaining gaps in the areas of service discovery, configuration and link management will be probably be plugged by various protocols and standards used within IP networks (for example, UPnP, Apple’s Bonjour, etc.). Traditionally, Wi-Fi has had problems with novice users configuring their networks (e.g. channel selection at the AP, enabling security, authentication of clients, etc.). The user experience has improved over the years, but still there are issues. It remains to be seen whether Wi-Fi Direct will meet the challenge here, but it is clear that Bluetooth successfully solved this problem many years ago.

4.7 Certification

Certification of Wi-Fi Direct is very similar to that used for current Wi-Fi Certification programs. It will be completely handled by the Wi-Fi Alliance.

Bluetooth 3.0+HS is more complicated, due to the fact that Bluetooth piggy-backs onto an 802.11 radio. The Bluetooth SIG has no wish to fully certify this radio in the same way as it does for a Bluetooth radio. Instead, it accepts a WFA Wi-Fi certification (for running Wi-Fi on an 802.11 radio) and adds some extra tests for AMP operation in its own certification procedure to cover the parts that WFA does not test.

4.8 Interoperability

One of the historical strengths of Bluetooth is device-to-device interoperability between applications. This is accomplished by means of Profiles, which sit between the top of the Bluetooth stack and the end-Application. Profiles are application specific, and define protocols and data structures for interfacing devices. Thus, there are profiles for printing, transferring objects (files), streaming voice, stereo audio and video, for keyboards and mice, for remote control functions, etc. Devices from different manufacturers, which have been certified as supporting the same profiles, look identical in the Bluetooth world. This gives OEM's a framework within which to design their products, and an interoperable mass market at which to target them.

Bluetooth 3.0+HS reuses the existing base of standard Bluetooth profiles. No special "high speed" profiles have been introduced (although some are being tweaked to improve performance) and the 802.11 AMP link is basically invisible at the profile level.

Wi-Fi Direct is quite different since application-level interoperability is not part of Wi-Fi culture and experience. The Wi-Fi Direct specification only covers the secure P2P transfer of frames of data from one device to another, plus power-saving features.

For classical Wi-Fi, a TCP/IP stack is normally run above the Wi-Fi stack and this is the basis of WLAN operation. TCP/IP can be used with Wi-Fi Direct to deliver data from Point A to Point B in an interoperable manner. For simple file transfer, FTP can be added. Other protocols exist for other applications; SMTP for email, Telnet for remote terminal access, HTTP for Web, etc. For streaming media over IP, several protocols have been developed; RTCP, RTSP, RTP, etc. Higher-level standards such as DLNA and UPnP impose order by specifying which underlying standards should be used for common scenarios and by certifying compliance. However, UPnP and DLNA are far from being universally deployed, and there is a danger that in the name of differentiation, OEM's will use non-interoperable, vendor-specific methods.

Bluetooth has always taken it upon itself to guarantee end-to-end interoperability for all sorts of different scenarios and use-cases. The price to pay is a heavy burden for Interoperability Testing and Certification, and a certain lack of flexibility (profiles are fixed).

Wi-Fi Direct is less ambitious, or more flexible, depending on your point of view. It separates the IP pipe from handling media objects and guarantees only IP-level interoperability. Other standards, outside of WFA but well-proven in the IP world, are used to handle the different application scenarios. Thus, the interoperability of Wi-Fi Direct audio, video, imaging and data applications could be a challenging task for handset operating system vendors. Outside of DLNA and UPnP, there is no centralization of interoperability and much more opportunity for things to go wrong.

As Wi-Fi attempts to move from the WLAN domain into Bluetooth's WPAN domain, it would seem that interoperability will be a major barrier and challenge. However, is the paradigm changing?

Mobile Phones, led by the Smartphone category, are incorporating two key, revolutionary features.

- Open OS and GUI (iPhone, Android, Symbian, Bada, plus Java, HTML5 etc)
- Apps downloads from an Apps Store.

Both of these features combine to make a smartphone resemble a PC, with the ensuing implications for interoperability. In this environment, it could be possible that Bluetooth profiles are being replaced by downloadable Apps. For example, a headset manufacturer with a new product is not

restricted to comply with a pre-defined profile, but can provide a downloadable smartphone App and GUI for his latest product. Of course, profiles continue to have value for entry-level phones with a closed OS and no Apps download capability, but this market segment also has less need of a high-speed P2P wireless link.

4.9 Audio/Video Streaming

Much of the comparison so far has been for transmitting bulk data from one device to another. What about the other major use case, that of streaming audio and video content? How do Bluetooth 3.0+HS and Wi-Fi Direct compare?

Satisfactory audio streaming is a much more difficult problem to solve than bulk data transfer. Apart from ensuring a minimum data-rate, it is necessary to meet various real-time constraints, ensure a good quality of service (QoS), and be extremely power-efficient for use on battery powered headsets and mobile AV sources. Good audio quality is ruined by the occasional click, pop or gap, and a listening time of several hours is mandatory.

Bluetooth deservedly dominates the world of mobile wireless audio. The High-Speed option is not necessary (1 Mbs is fine for audio) and Bluetooth provides a host of features to support audio streaming.

- Frequency hopping that provides a robust link that is highly resistant to ISM band interference
- A synchronous Tx/Rx protocol with error handling (eSCO)
- Mandatory voice (CVSD, mSBC) and stereo (SBC) codecs for interoperability
- Dedicated voice (HFP) and stereo (A2DP) audio profiles for interoperability. These are quite sophisticated, allowing several audio parameters to be negotiated between different devices whilst guaranteeing interoperability. There are also profiles for remote control of audio functions (skip track, volume up, ...etc)
- Optimized and proven products to minimize cost, power, BOM and size for Bluetooth audio products, especially headsets.

Wi-Fi is capable of acting as a bearer for audio of course, but it suffers from several disadvantages. It is an asynchronous, best-effort link which offers no QoS guarantees, and it has no dynamic frequency hopping (only static channel allocation). It does have a larger bandwidth due to higher speed, but this also leads to significantly higher power consumption. Above all, it has no profiles, relying instead on other industry standards, and it does not mandate specific codecs. This "free for all" means virtually no interoperability except for a few special situations such as VoIP, where the interoperability of the Wi-Fi voice applications in the handset was facilitated by the existence of a single UMA standard. DLNA is addressing this challenge, but although Wi-Fi is used for streaming music in the home, the systems are generally closed to each vendor.

Video streaming is very similar to audio, but at a higher speed and with tighter constraints (including synchronization to audio streaming). Here, High Speed operation of at least 10Mbps is mandatory for even medium-quality audio. HD video provides a challenge for both Bluetooth 3.0+HS and Wi-Fi Direct. As for audio, Wi-Fi offers a solution, but Bluetooth offers an interoperable solution with better QoS. The power situation is similar, since the same 802.11 radio is the bearer.

5 Discussion

In the past, Bluetooth and Wi-Fi have been complementary and have established a large installed base in different domains. On the performance side, there is not a lot to choose between Bluetooth 3.0+HS and Wi-Fi Direct since an 802.11 radio is used for high speed transfer in both systems. The deciding issue is expected to be the different origins and installed bases of Bluetooth and Wi-Fi.

Bluetooth has dominated wireless connectivity in mobile phones thanks to its low cost, power economy and audio streaming to headsets and car-kits. It also appears in games controllers and in PC's for wireless mice and keyboards. Wi-Fi has not been a threat due to its much higher power consumption and lack of ad-hoc connections.

Wi-Fi's stronghold is in PC's for wireless internet and networking, but it is rapidly expanding into diverse areas such as printers, media centers, digital cameras, music players and, significantly, mid and high-end mobile phones. Bluetooth has not threatened due to its much lower speed.

Speeding up Bluetooth and revamping Wi-Fi with low-power and ad-hoc capabilities brings them head-to-head for the first time. They will bid to be the technology of choice for wirelessly moving multimedia content between their installed bases; digital cameras, mobile phones, PC's and Home Entertainment systems (TV and audio). The big question is "which will prevail and where should we make our bets for the future?" Here are our predictions for how the market will evolve and which choices will be made.

Laptop/Netbook PC products are 100% Wi-Fi enabled. Bluetooth is also present to a much smaller degree either on the motherboard or via a USB dongle, but its use is usually constrained to low-power wireless peripherals (keyboard, mouse), audio, and small amounts of data transferred to/from mobile phones. As noted earlier, current Wi-Fi hardware only requires new firmware, so it is expected that the PC world will massively implement Wi-Fi Direct via a "service-pack" style upgrade of the Wi-Fi subsystem. This method of deployment means that the whole PC Wi-Fi installed base will support Wi-Fi Direct almost overnight. Bluetooth High Speed has very little added value and will not be installed, although traditional Bluetooth applications will continue to be supported for a while..

Printers are usually connected via a wired link, typically Ethernet or USB. However, wireless printers are becoming popular and here Wi-Fi is the de-facto standard. Bluetooth has always offered profiles and support for printing, but its low speed has been a killing handicap and it has rarely appeared in this application. It is expected that printers will remain a Wi-Fi domain and new models will have upgraded firmware that supports Wi-Fi Direct. There is little motivation to add an extra chip and associated software to support High Speed Bluetooth.

Digital cameras are capable of generating large amounts of data, but have special constraints for size and battery capacity. For these reasons a USB connection is normally used to offload photos to PC's. Wi-Fi is supported on some models, and is used for uploading content directly to web sites such as Facebook and Picasa via a Wi-Fi access point. An upgrade to support Wi-Fi Direct would be very attractive since it would allow downloads to the home PC, smartphones and TV's. Bluetooth's dual-radio approach is unlikely to be of interest.

Home Entertainment devices encompass TV's, Hi-Fi audio, set-top boxes and AV distribution systems. It is clear that TV's and set-top boxes will converge and merge with PC's and Internet. They are therefore expected to follow the same path as described above for PC's and

become a Wi-Fi Direct domain. Wireless AV distribution is currently confined to beaming audio around the home from a central server. DLNA plays a strong role here using Wi-Fi as the recommended wireless transport. A firmware upgrade to add WiFi-Direct would allow nomadic music players to be connected to the home DLNA network in an ad-hoc manner.

All of the previous segments are dominated by Wi-Fi, with Bluetooth in a minority position or absent. The final market segment, which is also the biggest, is quite different.

Mobile Phones are a stronghold of Bluetooth, but with Wi-Fi appearing in increasing numbers. For high speed, peer-to-peer content transfer, phone OEM's have the choice of implementing either Bluetooth High-Speed or Wi-Fi Direct. Bluetooth is already used for small bulk transfers (business cards, single photos, files < 5 Mb), so a natural upgrade would be to use a faster version of Bluetooth and reuse the profile implementations and applications. However, there are many attractive use cases for transferring mobile phone content (photos, video clips, music, etc) to the home PC, to share on a TV display, to a printer, or to FaceBook. As noted above, these are all Wi-Fi domains which are expected to upgrade to WiFi-Direct and not to Bluetooth High Speed. Today, it seems that mobile phone manufacturers are sitting on the fence. Despite the availability of the Bluetooth3.0+HS specification for over a year there has been no detectable move to add High-Speed Bluetooth to new phone models.

The logical conclusion is that Wi-Fi Direct will be the winner in the high-speed WPAN domain. However, Wi-Fi Direct is new and unproven, so there are a few significant hurdles that it has to clear in order for this to become reality.

The first challenge is to provide a secure, easy-to-use mechanism for connecting devices in an ad-hoc fashion. It is the combination of "secure" and "easy-to-use" that is tricky, and this is completely new territory for a WLAN technology such as Wi-Fi. Bluetooth's solution is tried and trusted, yet the most common user complaint is difficulty in pairing devices. Wi-Fi Direct must do better.

The second challenge is interoperability. Following the example of connecting USB devices to PC's, people will expect to have "plug and play". If different devices don't automatically work together, or require complex set-up, Wi-Fi Direct will be handicapped. This is a big danger because Bluetooth has demonstrated what is possible and has set high standards.

The third challenge is to deliver on power saving, so that Wi-Fi Direct activity does not drain the battery on mobile devices. Whilst Wi-Fi will never beat Bluetooth in this domain, the power-saving scheme in Wi-Fi Direct plus the continuing evolution to take advantage of lower power silicon processes should be adequate for use on battery powered devices.

6 Conclusion

Bluetooth High-Speed is expected start appearing in products late in 2010, whereas Wi-Fi-Direct will deploy at the beginning of 2011. Initially, Bluetooth High-Speed and Wi-Fi Direct will co-

exist, often inside the same product. High-end phones and Netbook PC's will continue to include both Bluetooth and Wi-Fi hardware to support their traditional use cases.

In the long run, Wi-Fi Direct will be the long-term winner for applications that require high data transmission rates. The growing convergence of smartphones, PC's and Home Entertainment pulls the market towards Wi-Fi's position of strength in the PC world where it is pervasive as a transport for various sorts of media content (audio, video, images and text) in a wide range of consumer devices. Although Bluetooth's installed base is numerically larger than Wi-Fi, it is also much narrower, being founded mainly on mobile phones and audio headsets. Access to the widest range of multimedia sources and sinks is the key to winning the battle, and here Wi-Fi is very strong. Another factor is Bluetooth's dual-radio approach versus Wi-Fi's firmware upgrade of existing single-radio hardware.

Although Bluetooth is unlikely to win the high-speed WPAN battle, it is not expected that it will disappear from the wireless landscape. Bluetooth will hold its position in mobile handsets for wireless headset applications and the recent Low Energy specification will allow it to address new markets such as medical, sports and industrial sensors, plus games and gadgets. Thus it is expected that Bluetooth's future will be medium/low speed, low power audio and data applications. Bluetooth 3.0+HS will be irrelevant within 2-3 years as Wi-Fi Direct completely replaces it for high speed data applications.

Looking even further out, it is possible that Wi-Fi Direct will threaten Bluetooth's traditional position in audio headsets and PC peripherals by means Wi-Fi Direct IC's that are optimized for low power operation. These could potentially replace Bluetooth headsets, mice and keyboards by Wi-Fi equivalents. Only time will tell ...