Local Area Networking Using Millimeter Waves

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Abstract

The enterprise network is migrating from 100 Mbps to 1 Gbps driven by the need for data rate, manageability, scalability, mobility and security. The last such migration occurred in the mid 1980s with the transition of the wired enterprise infrastructure from 10 Mbps to 100 Mbps. The current migration will enable the deployment of Gigabit-Ethernet-to-the desktop which translates to the delivery of the next generation of bandwidth intensive services. The existing and up coming 802.11n wireless LAN standard cannot keep pace with this development in the wired LAN network. This is because of limitations imposed by limited bandwidth, frequency congestion, and the need to provide backward compatibility with legacy standards. On the other hand, the Gigabit Ethernet wired network cannot provide mobility. It will have high network deployment and operational costs.

Canada, Japan and the U.S. have allocated 7 GHz of unlicensed spectrum in the 60 GHz band. The wireless technology in this band has considerably matured and it can now compete with the Gigabit Ethernet wired infrastructure and provide mobility. However, the propagation characteristics at millimeter waves are very different from that at 2.4 GHz and 5 GHz. Therefore, the network topology must be re-examined to consider the unique propagation behavior at 60 GHz. Operating at 60 GHz and higher frequencies will require a new class of modem that is tolerant to non-linearity and phase jitter, and provide spectral efficiency better than QPSK. This modem must consume low power for battery operated applications, and must be realizable on a SiGe and CMOS structure. Small antenna size enables development of smart antennas that can considerably improve network reliability. The MAC layer must be non-proprietary and, at the same time, provide high data rate throughput to support a wide range of applications.

The MAC and 60 GHz PHY layers together can support a wireless network that seamlessly operates indoors (WLAN) and outdoors (campus network). This translates to lower operating and deployment costs, and provides the ability of implementing a centralized security policy across the network. The modem and antenna technology at 60 GHz can be easily scaled to 70 GHz, 80 GHz and 90 GHz. Each of these bands has unique propagation behavior and, therefore, can be overlaid over each other without mutual interference for indoor and outdoor applications.

Millimeter wave always had great potential, but high costs, immature technology, and niche applications have hindered its growth. The applications and technology in the 60 GHz band will change this mold.

The Holy Grail for the enterprise network is to have a wireless technology that will replace the wired infrastructure. The wireless offers mobility that the wired network cannot provide. Additionally, the wireless network enables rapid adds and moves as offices are setup and dismantled, and personnel are moved around. In such a dynamic environment, the cost to deploy and manage the wireless network will be lower than the wired one. Unfortunately, the existing and forthcoming wireless technologies cannot replace the emerging wired infrastructure. There are a number of reasons for this. One, Gigabit Ethernet switch is replacing Fast Ethernet as the preferred switch in the enterprise. This trend will accelerate as the cost difference between the two narrows. Two, Gigabit Ethernet RJ-45 port will become standard on all desktops and laptops, thus making Gigabit-Ethernet-to-the-desktop a possibility. Three, the sales of 10 Gigabit Ethernet switch grew for three consecutive quarters. Although the market for 10 Gigabit Ethernet enterprise switch is considerably smaller than that of the Gigabit Ethernet, its emergence in the enterprise is astonishing as it is usually relegated to the core of the Internet network. Four, the IEEE has a task group (802.3an) that is working to create a standard to transport 10 Gbps over copper. These market trends indicate that future enterprise networks will have an aggregate capacity of 10 Gbps in the core and 1 Gbps to the desktop. Existing and forthcoming wireless technology cannot keep pace with these trends and, thus, cannot replace the wired infrastructure.

The 802.11n will certainly push the limits of data rate to about 300 Mbps, but it is certainly not a wire replacement technology. It cannot keep pace with the trends and limitations described in the earlier paragraphs. The 60 GHz band is the only region in the unlicensed spectrum that can provide a data rate of 1 Gbps minimum. Figure - 1 shows the frequency allocation in Canada, Japan and the United States.

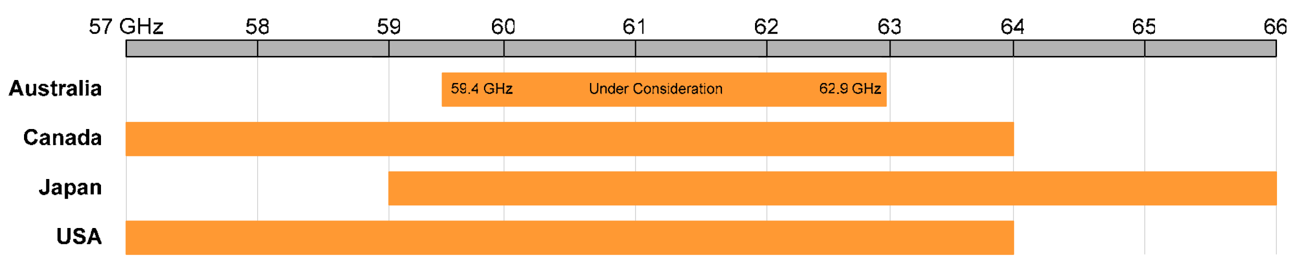

Figure 1 – Unlicensed Frequency Allocations

Designing and developing a 60 GHz local area network is challenging because the propagation characteristics at 60 GHz is different from that at 2.4 GHz. The propagation at 60 GHz is much like quasi-optical. Building and office materials have significant impact on the attenuation, and multipath delay spread from reflections are different from that at 2.4 GHz. Shadow fading due to human traffic and other obstacles are very pronounced at 60 GHz. This frequency band also has an interesting natural phenomena – the oxygen in the atmosphere absorbs the energy (about 15 dB/Km). Considerable work has been done in quantifying the attenuation, delay spread and shadow fading for various indoor environments, and in understanding the absorption and attenuation by atmospheric gases and particulates. This understanding of the propagation characteristics, along with the emergency of SiGe and CMOS at 60 GHz, will enable the development of low cost devices for a broad range of applications. The first mass market application for 60 GHz will be in providing connectivity among consumer electronics and computing devices. In anticipation of a demand for this technology, the IEEE has created a task group, 802.15.3c, to develop a physical layer standard.

The 802.15.3c standard is not applicable for the enterprise wireless LAN. For one, the availability requirement is about 90%, which translates to an outage of 876 hours/year or 72 hours/month. This outage is unacceptable for the enterprise. Secondly, the 802.15.3c provides peer-to-peer connectivity in a radius of 10 meters from the user. Such a peer-to-peer architecture does not lend itself for scalability and manageability. The existing infrastructure architecture, as seen in the deployment of 802.11b/g network in the enterprise, addresses all the short comings described above, but it does not lend for the millimeter wave frequencies. A new type of infrastructure based architecture is required which considers the unique propagation characteristics at 60 GHz. The requirements for this architecture are (a) aggregated data rate of better than 10 Gbps, (b) Gigabit-Ethernet-to-the-desktop, (c) high availability, and (d) high reliability. The architecture must exploit the high frequency reuse provided by the atmospheric gaseous absorption and attenuation by office and building materials.

In order to achieve high aggregated bandwidth, the 7 GHz spectrum is broken into 12 non-overlapping and co-existing channels, each able to support a burst rate of 1 Gbps. The spectral efficiency of each channel under the proposed channelization plan is better than 2 bps/Hz. Such efficiency cannot be achieved by ASK and QPSK. Higher order modulation schemes have tight linearity and phase noise requirements which make them uneconomical. Therefore, a new class of modulation scheme is required for millimeter wave applications that is less sensitive to linearity and phase noise. The proposed modulation is a bipolar SSB coding with a pilot tone. This scheme, with FEC, provides a minimum receiver sensitivity of about -70 dBm. Low receiver sensitivity is the only way to effectively increase link distance because regulatory requirements place a limit on the power into the antenna and antenna gain. Figure – 2 shows the architecture of a network that can provide high availability and reliability. 802.16 MAC was considered because it was designed from the inception with QoS in mind. The infrastructure part of the network consists of wireless access points (WAPs), aggregator and stations (STNs). All wiring (Cat 6 cable or multimode fiber) from the wireless access points distributed throughout the enterprise are terminated at the aggregator, which resides in the network operations center of the enterprise. This architecture eliminates the need for closet switches which are required in 802.11a/b/g networks. The aggregator is a layer-2 device whose broad functions are described on Figure – 2. The proposed TDD system is controlled by the aggregator which can be a blade in the enterprise router. This ensures manageability and the wireless architecture facilitates scalability.

The WAPs illuminates a region, with each WAP operating in a specific channel. This cellular like architecture mitigates shadowing problems and provides mobility. Each WAP has beam shaped antennas which ensures that the gain is minimum close to WAP and maximum at a distance of 50 m typical for indoor application. When a station enters the coverage area or it is powered on, it executes an algorithm to discover the WAPs and reports the signal-to-noise ratio of the link to the aggregator. In order to simplify explaining the functioning of this system, this paper will not address security and authentication processes. The aggregator has a lookup table containing the signal-to-noise ration (SNR) of each wireless link in the coverage area. This table is periodically refreshed. Thereafter, the control and management of the stations falls under the purview of the aggregator. A STN can transmit or receive at any one of the 12 channels. It employs an intelligent beam switched antenna that has 360º coverage in azimuth. A STN can communicate with any WAP it can 'see' based on the SNR. The problem with this approach is that STNs can converge to a single AP, thus overloading it. To prevent this from occurring, the aggregator and the WAPs execute a load balancing algorithm which allocates cost to each WAP. A STN communicates with the WAP with the lowest cost. If the SNR of this link is marginal, it can transmit a duplicate packet to another WAP with the next lowest cost. Built on top of the MAC is the diversity management layer which essentially provides multi-point-to-multi-point capability. The diversity based on frequency, space and time is essential to provide superior availability and reliability comparable to that offered by the wired technology.

The above architecture can replace the wired infrastructure. This architecture can be used indoor or outdoor, typically in a campus network. It can be modified to enable integration into a WiFi network, thus backhauling the WiFi traffic at 1 Gbps and providing Gigabit-Ethernet-to-the-desktop capability.

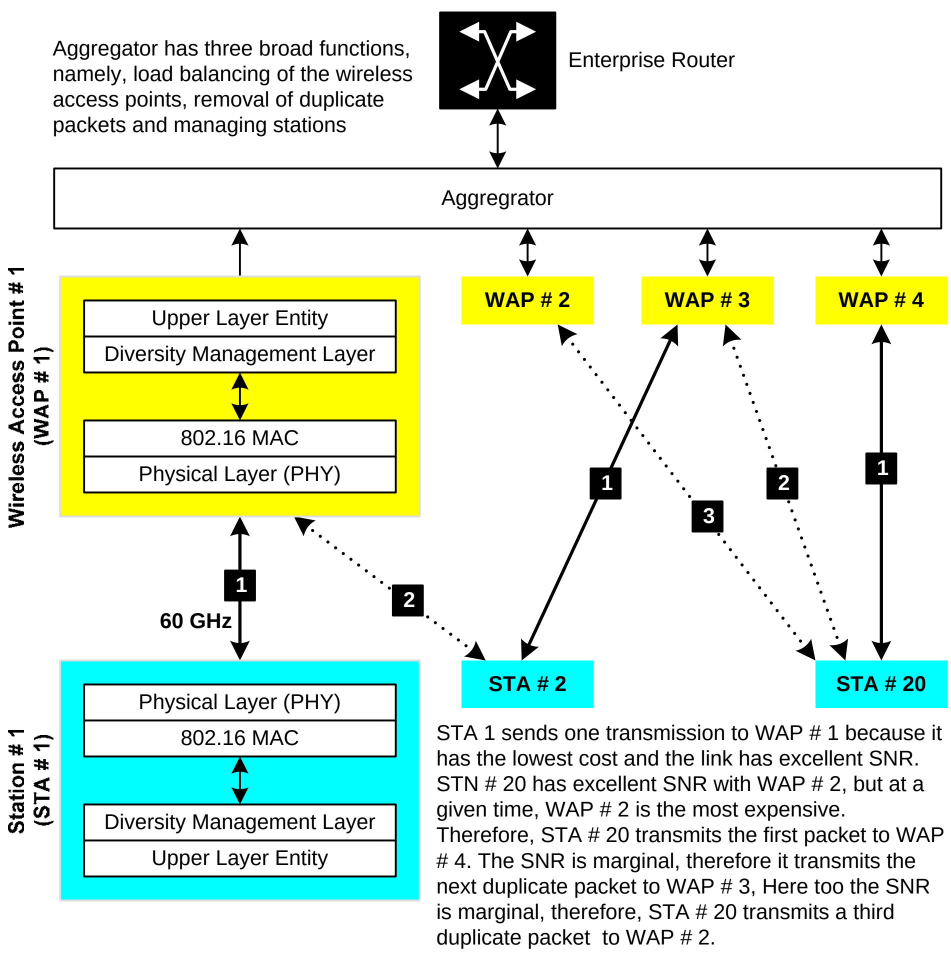

Figure 2 – Top Level System Architecture