WIRELESS TECHNOLOGIES

ZIGBEE, BLUETOOTH, WIRELESS LAN, WIMAX

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ZIGBEE

Introduction

ZigBee, shown in Figure 1, began to conceive around 1998 and was supported by Philips Semiconductors in the summer of 2003. It is a wireless mesh networking standard, maintained by the ZigBee Alliance, an association of companies, who also publishes the ZigBee standard. ZigBee offers a high level communication protocols with low cost, low power consumption, and high reliability resulting from mesh networking. ZigBee's main targets are the radio-frequency applications with low data rate, long battery life, and secure networking requirements.

Figure 1. **ZigBee**[1]

Protocol Architectures

The ZigBee protocol has been created and ratified by the ZigBee Alliance. The protocol was designed to provide an easy-to-use wireless data solution with multiple characteristics such as low-power consumption, support multiple network structure, and secure connections, and to carry data through radio-frequency environments, exist in commercial and industrial applications.

ZigBee protocol features[2] include:

- Low-duty cycle, resulting in longer battery life
- Low latency
- Support for multiple network topologies, including static, dynamic, star, and mesh

- Modulation technique of Direct Sequence Spread Spectrum (DSSS)
- Up to 65,000 nodes on a network
- 128-bit AES or Advanced Encryption Standard encryption algorithm, resulting in better security of the connections between devices
- Collision avoidance
- Link quality indication
- Clear channel assessment
- Retries and acknowledgements
- Support for guaranteed time slots and packet freshness

ZigBee is built on the IEEE 802.15.4 standard, developed at the Institute of Electrical and Electronics Engineers. IEEE 802.15.4 that is related to ZigBee can be separated into 4 sub-standards as follow:

- IEEE 802.15.4-2006
- IEEE 802.15.4a-2007
- IEEE 802.15.4c-2009
- IEEE 802.15.4d-2009.

Basically, IEEE 802.15.4 standard defines the specific requirements for Wireless Medium Access Control (MAC) and Physical Layer (PHY) for Low-Rate Wireless Personal Area Network (WPAN).

ZigBee's layered stacks consists of 2 main parts as shown in Figure 2: The IEEE standard 802.15.4 at the bottom which contains the physical layer and medium access control, and the ZigBee specification at the top which contains network layer, application layer, ZigBee device objects (ZDO's), and manufacturer-defined application objects.

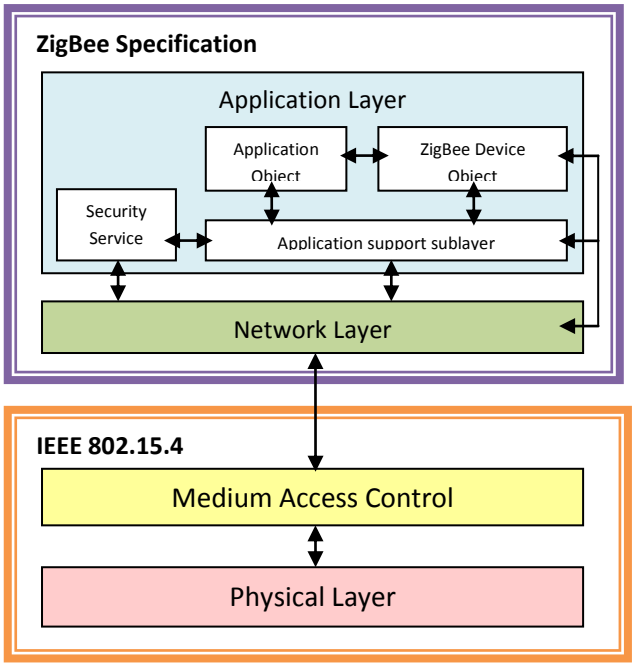

Figure 2. **ZigBee Layered Stack**

For physical and MAC layer, it is usually specified to operate at license free band at 2.4 GHz, however, license free band at 915 MHz is often used in North America, and license free band at 868 MHz is used in Europe. Since the system may have to work in severe environments, special features such as a quality assessment, receiver energy detection, and clear channel assessment are implemented in order to enhance the reliability of the operation. CSMA or Carrier Sense Multiple Access technique is also used to determine a proper transmission time, hence unnecessary clashes are avoided.

ZigBee's network layer works as a controller of the MAC sublayer and provide a proper interface to the application layer. It is able to support three types of topologies: both star network, cluster tree or hybrid networks, and generic mesh network. Star network is commonly used since it is the simplest one. Mesh network offers high reliability since many different routes can be obtained. Cluster tree or hybrid network is the combination of star and mesh networks.

The application layer is the highest-level layer which provides an interface between ZigBee and the end-user. There are 2 main components: ZigBee Device Object or ZDO, and application support sublayer or APS. ZDO works as a device controller, while ASP connects the network layer to the components of the application layer. In addition, ZDO's main responsibilities are to define a role of the current coordinator or end device and to detect new devices. ASP is responsible for finding appropriate services for each device.

Data Transmission

For the data transmission of ZigBee, Direct Sequence Spread Spectrum or DSSS is used as a modulation technique. The data is divided and is transferred in packets with a maximum size of 128 bytes.

According to the physical layer and MAC layer, ZigBee is able to operate at 3 frequency bands:

- 2.4 GHz

  This frequency is used worldwide. With 16 channels, it offers the maximum data rate of 250 Kbps and the bandwidth of 5 MHz for each channel.
- 915 MHz

  This frequency is used in North America. With 10 channels, it offers the maximum data rate of 40 Kbps.
- 868 MHz

  This frequency is used in Europe. With only 1 channel, it offers the maximum data rate of 20 Kbps.

Transmission Media

The 802.15.4 standard is defined as a short-range standard, hence, its goals are to provide ultra-long battery life with low transmit power. The maximum transmitter output power is only 0 dBm or 1 mW and the transmission range is from 10 to 75 meters. The transmission range can go up to 1500 meters for ZigBee Pro.

ZigBee antennas comprises of three models. For applications that demand increased signal strength, the slightly longer rubber ZigBee antennas is desired with a gain of up to 9 dBi. For designers of ZigBee systems, embedded and peripheral GSM antennas are used. There are still a range of adaptor cables use for connecting the connectors commonly used on preassembled ZigBee modules to external antenna.

Signal Encoding Techniques

ZigBee's signal encoding technique is vary depending on the frequency band of the device.

For 2.4 GHz devices, binary phase-shift keying or BPSK encoding technique is used. As shown in Figure 3, the phase of base signal is changed in response to the data signal. With BPSK, 2 phases can encode 1 bit per signal, hence, it provide a simple encoding technique. However, BPSK's disadvantage is the lack of flexibility.

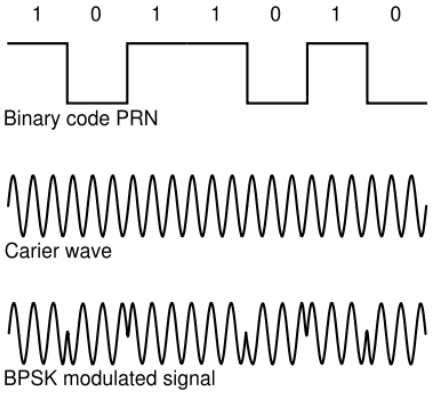

Figure 3. **Binary Phase-Shift Keying**[8]

Offset quadrature phase-shift keying or O-QPSK is used with 915 MHz and 868 MHz devices. In this case, instead of using 2 phases like BPSK, O-QPSK uses 4 different values of the phase to transmit the data signal. As a result, lower amplitude fluctuations are obtained.

Errors

ZigBee uses ARQ is an error-control method for data transmission. ARQ uses acknowledgements and timeouts to achieve reliable data transmission over an unreliable service. If the acknowledgement is not received by the source within the timeout interval, the data is retransmitted.

Applications & Usage

Since ZigBee offers a low-cost, low-power wireless network, it is an ideal for the install-and-forget type of devices.

ZigBee is used in the following technology:

- Sensors & Controls
- Home networking
- Industrial networks
- Remote metering
- Automotive networks
- Interactive Toys
- Active RFID / Asset Tracking

ZigBee is commonly used to automate household task in China. In the future, it is expected to be used in average American home, which may allow people to communicate with each other freely and help regulate common tasks.

Cost

The cost of equipment can range from $15 - $30 depending on the manufacturers and type of Zigbee device.

Protocol Architecture

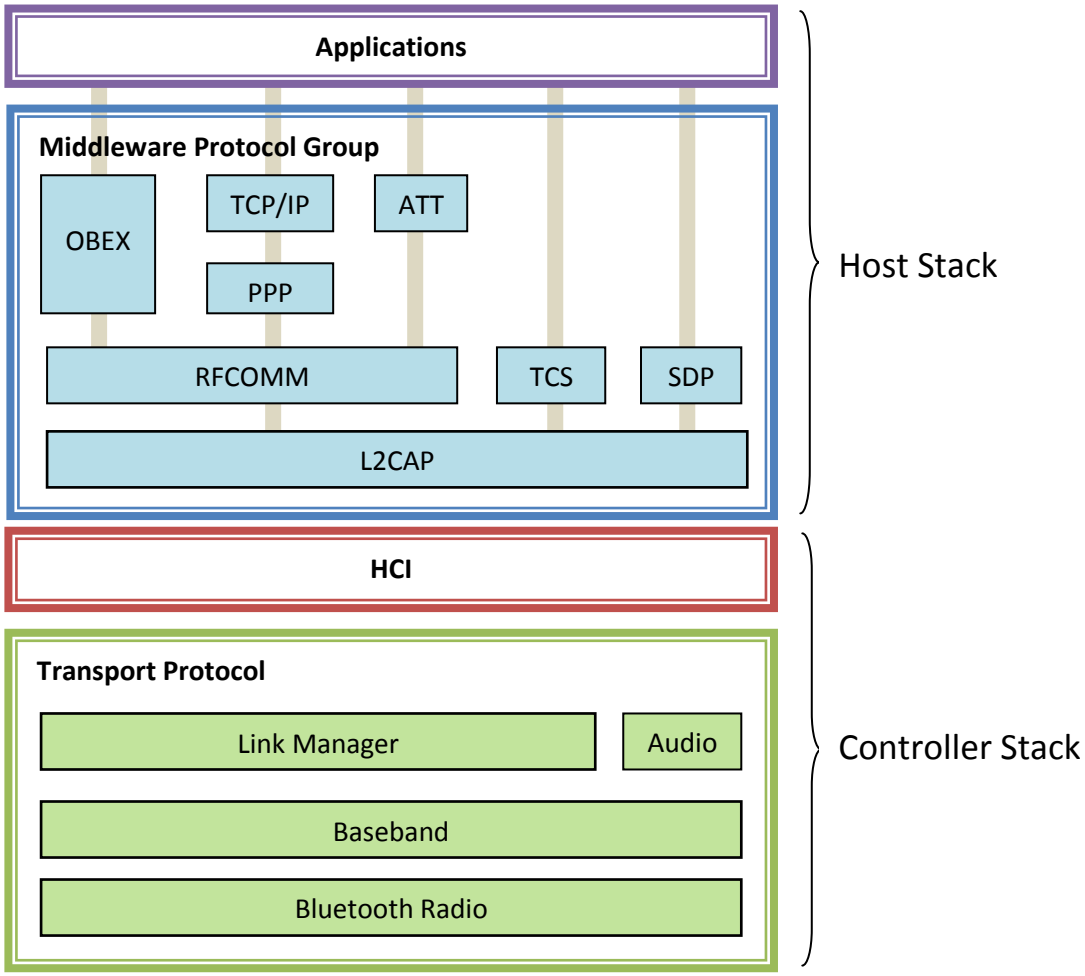

Figure 4. **Bluetooth Layered Stack**

Bluetooth's layer protocol architecture consists of 2 main parts, as shown in Figure 4. The layer is divided into controller stack and host stack.

Controller stack contains the timing critical radio interface. Following lists are main protocols within this stack:

- LMP (Link Management Protocol)

  It is used as a controller of a radio link between two devices.

- HCI (Host/Controller Interface)

  It provides standard for communicating between the host stack (e.g., a PC or mobile phone OS) and controller (Bluetooth IC).

Host stack deals with high-level data with the following main protocols:

- L2CAP (Logical Link Control & Adaptation Protocol)

  It works as a messenger passing packets to either the Host Controller Interface (HCI) or directly to the Link Manager. It multiplexes and manages the data between higher-level protocols, segments and reassemblies the packets, and provides one-way transmission management of multicast data to a group of other Bluetooth devices.

- Service Discovery Protocol

  SDP allows a device to find services supported by other devices and applications to determine the characteristics of services.

- RFCOMM

  Radio frequency communications (RFCOMM) is cable replacement protocol. It creates a virtual serial data flow and offers a reliable data stream to the user. RFCOMM provides binary data transport and copy EIA-232 control signals over the baseband layer.

- BNEP (Bluetooth Network Encapsulation Protocol)

  It is used for transfer another protocol stack data through L2CAP channel. Main purpose is the transmission of IP packets in the Personal Area Networking Profile.

- AVCTP (Audio/Visual Control Transport Protocol)

  It is used the remote control to transfer AV/C commands to L2CAP channel. Also the music control buttons on stereo headset use this protocol for the music player.

- AVDTP (Audio/Visual Data Transport Protocol)

  It is used for the audio and video distribution profile to flow music and sound to stereo headsets over L2CAP channel.

- Telephony control protocol

  Telephony control protocol-binary (TCS BIN) is the bit-oriented protocol defines the call control signal for creates voice and data calls between Bluetooth devices. TCS BIN defines process management for groups of Bluetooth TCS devices that used only mobile phone profile failed to attract implementers.

- Adopted protocols

  Adopted protocols are defined by other standards-making another company and combine to Bluetooth's protocol stack, allow creating protocols only necessary.

  Some examples of adapted protocols:

  - Point-to-Point Protocol (PPP)
  - Internet standard protocol for transport IP datagrams over a point-to-point link.
  - TCP/IP/UDP
  - Base Protocols for TCP/IP protocol suite

- Object Exchange Protocol (OBEX)
- Session-layer protocol for the exchange of objects, providing a model for object and operation representation
- Wireless Application Environment/Wireless Application Protocol (WAE/WAP)
- WAE specifies an application framework for wireless devices and WAP opens standard to provide mobile users access to telephony and information services.

Bluetooth is a radio frequency standard for a low-cost, very low-power, and short-range frequency-hopping radio system. Its protocol implements IEEE 802.15 standard, developed at the Institute of Electrical and Electronics Engineers. The IEEE 802.15 is a network standard for an inexpensive, short range, low power communications protocol, which in this case in Bluetooth.

Data Transmission

Bluetooth communicates on a frequency between 2.402 GHz and 2.480 GHz. It is a packet-based protocol with a master-slave structure. One master may communicate with up to 7 slaves in a piconet and all devices share the master's clock. In the simple case of single-slot packets, the master transmits in even slots and receives in odd slots; the slave converses, receives in even slots and transmits in odd slots.

The maximum data rate of Bluetooth can be up to 721 Kbps in its basic form and offers up to three voice channels. It implements a technique called spread-spectrum frequency hopping and supports a total bandwidth of 1 Mb/sec.

Transmission Media

Bluetooth can be divided into 3 groups according to the communication range required. The Power Class 1 can transmit at the maximum distance of 100 meters with a maximum output power of 20 dBm. Power Class 2 can transmit at a range up to about 10 meters, with a maximum output power of 4 dBm. Finally, Power Class 3 which is able to transmit at the distance of 10 centimeters with a maximum output power of 0 dBm.

Bluetooth antennas are classified in Table A. below.

Antenna Type	Performance	Profile	Cost	Physical Size
Stub helix or monopole	Good bandwidth and efficiency, does not require matching network.	High: Projects from the side of the PCB	High	2.4 GHz antenna is approximately 15 mm long, but projects. Does not need ground plane to function.
Surface-mount ceramic chip	Reasonable performance on λg/4. Small bandwidth and reduced efficiency. Can become detuned during handling	Low: Can be machine mounted during assembly, no more than 0.5 mm thick	Medium	Element for 2.4 GHz is approximately 12 mm long, but needs ground area and clearance around active region.
Printed inverted-F or other printed types	Reasonable performance on λg/4. Small bandwidth and reduced efficiency. Can become detuned during handling	Lowest: Printed on PCB	Low	Element for 2.4 GHz is approximately 25 mm long, but needs ground area and clearance around active region.

Table A. **Bluetooth Antennas**[11]

Signal Encoding Technique

The techniques and notations are already available for specify the required data structures in machine (encoding) independent way, most notable Abstract Syntax Notation 1 (ASN.1). Such ASN.1 protocol descriptions can be used in combination with standardized encoding rules the Basic Encoding Rules (BER) and the Packed Encoding Rules (PER). The new application areas general encoding rules are not efficient or flexible. That is the reason to make some standards using informal non-standard solutions such as tables to specify these required new encoding rules. Informal encoding solutions normally are not directly machine-processable and this together with lack of tool support often makes them extremely easy to error.

The goal of the ASN.1 Encoding Control Notation (ECN) is replace informal encoding schemes with a standardized machine processable solution. It will be powerful and flexible enough to handle the encoding needs of present and future application areas.

Errors

Three types of error correction are implemented in Bluetooth systems:

- 1/3 rate forward error correction (FEC)
- 2/3 rate FEC
- Automatic repeat-request (ARQ)

FEC is a technique for detecting and correcting errors by adding a small number of extra bits. It can be divided into 2 versions, 1/3 FEC and 2/3 FEC. The 1/3 FEC is a simple 3-times repetition of each info bit, while the 2/3 FEC is a (15,10) shortened Hamming code.

ARQ is an error-control method for data transmission that uses acknowledgements and timeouts to achieve reliable data transmission over an unreliable service.

Applications & Usage

- Control communication between a mobile phone and a hands-free headset.
- Wireless networking between PCs in a confined space and where little bandwidth is required.
- Wireless communication with PC input and output devices Transfer of files, contact details, calendar appointments, and reminders between devices with OBEX.
- Replacement of wired serial communications in test equipment, GPS receivers, medical equipment, bar code scanners, and traffic control devices.
- For controls where infrared was traditionally used.
- For low bandwidth applications where higher USB bandwidth is not required and cable-free connection desired.
- Sending small advertisements from Bluetooth-enabled advertising hoardings to other, discoverable, Bluetooth devices.

- Wireless bridge between two Industrial Ethernet (e.g., PROFINET) networks.
- In game consoles, Nintendo's Wii and Sony's PlayStation 3 and PSP, use Bluetooth for their respective wireless controllers.
- Dial-up internet access on personal computers or PDAs using a data-capable mobile phone as a wireless modem.
- Short range to transmission of health sensor data from medical devices to mobile phone, set-top box or dedicated telehealth (delivery of health-related services and information via telecommunications) devices.
- Allowing a DECT phone to ring and answer calls on behalf of a nearby cell phone
- Real-time location systems (RTLS) are used to track and identify the location of objects in real-time using “Nodes” or “tags” attached to, or embedded in the objects tracked, and “Readers” that receive and process the wireless signals from these tags to determine their locations.

Cost

Bluetooth devices use low-cost transceiver microchips that make the cost of manufacturing Bluetooth open devices is low. Bluetooth chips are estimated to cost around $4 to manufacture. The results for the prices of consumer Bluetooth devices are low.

Since Bluetooth technology operates on an unlicensed radio spectrum, it is no charge for communicate between two Bluetooth devices.

WIRELESS LAN

Protocol Architectures

Wireless LAN implements IEEE 802.11a, b, and g standard, developed at the Institute of Electrical and Electronics Engineers. IEEE 802.11 can be separated into 3 sub-standards as follow:

- IEEE 802.11a
- IEEE 802.11b
- IEEE 802.11g

802.11 networks are organized in two ways: Infrastructure mode (BSS) and Ad-hoc network (IBSS). In BSS, there is a station acts as a master with all the other stations associating to it. But for IBSS, there is no master and stations communicate directly.

Wireless LAN has the following protocol features:

- Required for devices to communicate
- Vendors have more marketable products
- Customers can insist on standards based equipment

Wireless LAN layered stack is divided into 3 layers: Lower layers of OSI model (Physical Layer), IEEE 802 reference (Upper Layer), and Logical link control (LLC) and Medium Access control (MAC) (Data Link Layer), as shown in Figure 5.

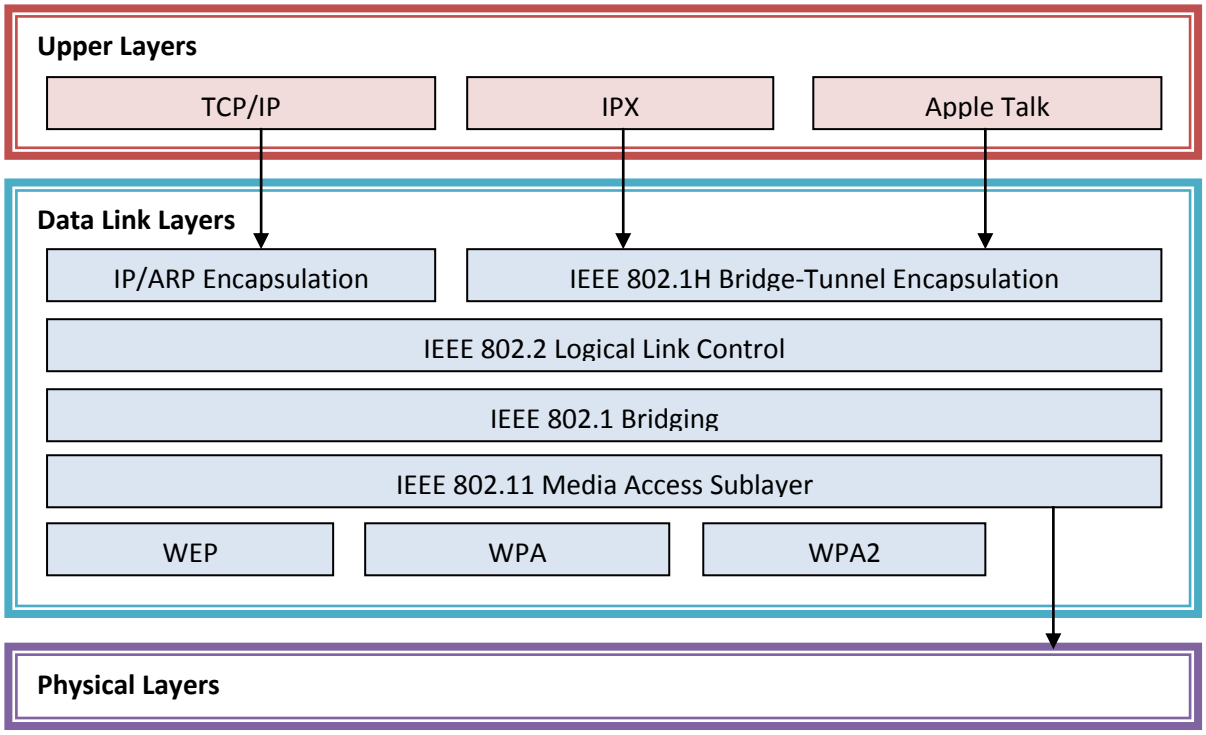

Figure5. **Wireless LAN Layered Stack**

Physical Layer of wireless LAN is defined by Lower layers of OSI model. Its jobs are to converts bits into electrical or optical signal and to transmit these signals over the hardware communication medium.

IEEE 802 reference defines the upper layer with TCP/IP protocol suite along with Data Link Layer. The Data Link Layer composes of logical link control (LLC), responsible for interacting with higher levels and controlling flow and error, and medium access control (MAC), responsible for assembling and disassembling of data into frame with address and error detection fields and governing access to transmission medium.

Data Transmission

The type of spectrum, frequency, bandwidth, and data rate depend on the IEEE 802 standard of each device. Wireless LAN comes with a bandwidth of 22 MHz and a 25 MHz channel separation.

For IEEE 802.11a, the device supports the data rate up to 54 Mbps with the transmission range of 60 to 100 feet and broadcasts in 5 GHz of frequency. Since the frequency used is differing from many other devices, hence, less signal interference is received. But the disadvantage is that the signal cannot pass through physical barriers.

For IEEE 802.11b, the device supports the data rate up to 11 Mbps with the transmission range of 70 to 150 feet and broadcasts in 2.4 GHz of frequency. The signal tends to be better than a-type at penetrating physical barriers but it may receive more signal interference due to the commonly used frequency among other devices.

For IEEE 802.11g, the device supports the data rate up to 54 Mbps, the same as a-type, with the transmission range of 65 to 120 feet, which is between a-type, and b-type. It broadcasts in 2.4 GHz of frequency like b-type, hence, more signal interference may be received.

Transmission Media

Transmit powers of wireless LAN are varying due to the differences in frequency. For frequencies of 5.15- to 5.25 GHz, the transmit power is +16.02 dBm. And for frequencies of 5.25- to 5.35 GHz, the transmit power is +23.01 dBm. The maximum transmit power for 802.11b transmissions is +30 dBm.

The transmission distance of wireless LAN depends on the standard of each device. For IEEE 802.11a, the transmission range is 60 to 100 feet, while IEEE 802.11b provides the transmission range of 70 to 150 feet. Lastly, IEEE 802.11g offerss the transmission range of 65 to 120 feet.

For Wireless LAN antennas, the omnidirectional plane which is an antenna having an essentially non-directional pattern in a given plane of the antenna and a directional pattern in any orthogonal plane is used.

Signal Encoding Techniques

For wireless LAN with low transmission rate, frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS) modulation techniques are used. FHSS transmits radio signals by rapidly switching a carrier among many frequency channels. DSSS divides data into packets and transmits the signal using full bandwidth.

For wireless LAN with higher transmission rate, orthogonal frequency division multiplexing (OFDM) encoding scheme is used. By using this scheme, data is divided into several parallel data streams or channels, one for each sub-carrier that operates with a conventional modulation scheme.

Errors

Wireless LAN implements signal strength indication circuit to monitor the received data signal strength in order to detect anomalies in the strength of the received data stream, typical of erroneous data. In addition, the data packets would imbed the error detection codes within the packets, so that the

resource and receiver can detect errors in the data packets. Hence, FEC is also used as a technique for detecting and correcting errors by adding a small number of extra bits. ARQ is an error-control method for data transmission that uses acknowledgements and timeouts to achieve reliable data transmission over an unreliable service.

Applications & Usage

- Personal computer LANs
- Back end networks
    - Interconnecting large systems (mainframes and large storage devices)
- Storage Area Networks
    - Separate network handling storage needs
    - Detaches storage tasks from specific servers
    - Shared storage facility across high-speed network
    - Hard disks, tape libraries, CD arrays
    - Improved client-server storage access
    - Direct storage to storage communication for backup
- High speed office networks
    - Desktop image processing
    - High capacity local storage
- Backbone LANs
    - Interconnect low speed local LANs

Cost

A wireless LAN implementation consists of 2 parts which are infrastructure costs for the wireless access points and user costs for the wireless LAN adapters.

Infrastructure costs depend primarily on the number of access points deployed. Range in price of the access point starts from $800.00 to $2,000.00. Wireless LAN adapters are required for standard computer platforms, and range in price from $200.00 to $700.00. The cost of installing and maintaining a wireless LAN is generally lower than the wired LAN's since wireless LAN eliminates the direct costs of cabling and the labor and the indirect costs of user downtime and administrative overhead.

Protocol Archtectures

WiMax implements IEEE 802.16 standard, developed at the Institute of Electrical and Electronics Engineers. IEEE 802.16 provide a standard for wireless communication system for metropolitan area network (MAN).

802.16 networks are organized in two ways: Infrastructure mode (BSS) and Ad-hoc network (IBSS). In BSS, there is a station acts as a master with all the other stations associating to it. But for IBSS, there is no master and stations communicate directly.

WiMax Forum is the group of industries who support and develop WiMAX technology worldwide. The purpose of the Forum is to create a standard for WiMax product with full interoperability.

WiMax layered stack has 3 main components which are physical layer, medium access control, and convergence layer, as shown in Figure 6.

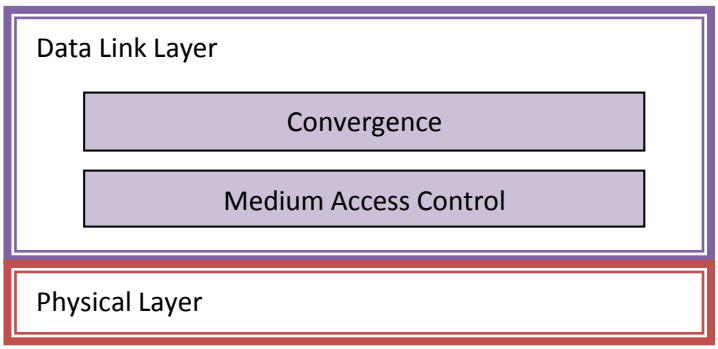

Figure 6. **WiMax Layered Stack**

The physical layer of WiMax is responsible for encoding and decoding of signals, preamble generation and removal, and bit transmission and reception.

The Data Link Layer contains Medium Access Control and Convergence layer. MAC functions include assemble data into a frame with address and error detection fields, disassemble frame and perform address recognition and error detection, and govern access to the wireless transmission medium.

Convergence layer encapsulates PDU framing of upper layers into native 802.16 MAC/PHY frames, maps upper layer's addresses into 802.16 addresses, translates upper layer parameters into native 802.16 MAC format, and adapt time dependencies of upper layer traffic into equivalent MAC service.

Data Transmission

WiMax system consists of 2 parts: A WiMax tower and a WiMax receiver. It can provide 2 forms of wireless service as the following:

- Non-line-of-sight

  The antenna from the computer is connected to the tower which is similar to WiFi service. The frequency range is low, about 2 – 11 GHz, so the wavelength transmission can avoid the physical obstructions.
- Line-of-sight

  The antenna is a fixed dish pointed straight to the tower. The connection is stronger than the non-line-of-sight and it uses higher frequencies up to 66GHz. Since the device operates at higher frequencies, therefore, less signal interference is received and it offers more bandwidth.

WiMax transmits at the data rate up to 70 Mbps which is split between users and supports the 2.5 GHz spectrum range.

Transmission Media

The transmit power of WiMax is vary depending on the type of WiMax. The basestations transmit at power levels of approximately +43dBm (20W), while mobile station (MS) typically transmits at +23 dBm (200mW).

The suitable antennas for WiMax technology are VECTOR Antennas which consists of sector antennas, high gain directional flat panel antennas, and omni antennas.

WiMax can provide broadband wireless access up to 50 kilometers for fixed stations and 5 to 15 kilometers for mobile stations.

Signal Encoding Techniques

WiMax implements dynamic burst algorithm modulation adaptive to the physical environment the radio-frequency signal travels through. The bursts can be easily decoded using digital signal processing when using this technique. It provides higher power per bit so that simpler accurate signal processing can be performed.

Errors

FEC is also used as a technique for detecting and correcting errors by adding a small number of extra bits. FEC compares the received data to the codeword the in order to detect and correct the error. ARQ is an error-control method for data transmission that uses acknowledgements and timeouts to achieve reliable data transmission over an unreliable service. WiMax uses selective repeat ARQ to retransmit the data that contains error.

Applications & Usage

WiMAX suits for the following potential applications:

- Providing portable mobile broadband connectivity across cities and countries through a variety of devices.
- Providing a wireless alternative to cable and DSL for "last mile" broadband access.
- Providing data, telecommunications (VoIP) and IPTV services (triple play).
- Providing a source of Internet connectivity as part of a business continuity plan.

Cost

The estimated cost for WiMax base stations is ranged from $10,000 for a bare-bones model to $150,000 for full-feature units. For customer premises equipment, the devices will be in the $250 range.

CONCLUSION

Comparison Table for some topics

Topics\Technology	ZigBee	Bluetooth	Wireless LAN	WiMax
Protocol Architectures				
Standards	IEEE 802.15.4	Bluetooth	IEEE 802.11	IEEE 802.16
Data Transmission				
Frequency				2 – 66 GHz
Data Rate				70 Mbps
Transmission Media				
Transmit Power				200 mW – 20 W
Distance			60-150 Ft	5 – 50 Km
Encoding Techniques				
				Dynamic burst algorithm
Errors				
	FEC	FEC	FEC	FEC Selective ARQ
Applications				
	Household Equipment	Mobile Device	Internet Network	Broadband Internet Connection
Cost				
			Access point: $800.00 - $2,000.00 Adapter: $200.00 - $700.00	Base Station: $10,000 – 150,000 Device: $250

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