International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:1, No:1, 2007

Emerging Wireless Standards - WiFi, ZigBee and WiMAX

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***Abstract*—**The world of wireless telecommunications is rapidly evolving. Technologies under research and development promise to deliver more services to more users in less time. This paper presents the emerging technologies helping wireless systems grow from where we are today into our visions of the future. This paper will cover the applications and characteristics of emerging wireless technologies: Wireless Local Area Networks (WiFi-802.11n), Wireless Personal Area Networks (ZigBee) and Wireless Metropolitan Area Networks (WiMAX). The purpose of this paper is to explain the impending 802.11n standard and how it will enable WLANs to support emerging media-rich applications. The paper will also detail how 802.11n compares with existing WLAN standards and offer strategies for users considering higher-bandwidth alternatives. The emerging IEEE 802.15.4 (ZigBee) standard aims to provide low data rate wireless communications with high-precision ranging and localization, by employing UWB technologies for a low-power and low cost solution. WiMAX (Worldwide Interoperability for Microwave Access) is a standard for wireless data transmission covering a range similar to cellular phone towers. With high performance in both distance and throughput, WiMAX technology could be a boon to current Internet providers seeking to become the leader of next generation wireless Internet access. This paper also explores how these emerging technologies differ from one another.

***Keywords*—**MIMO technology, WiFi, WiMAX, ZigBee.

I. Introduction

THE first thing an investor needs to determine is what is truly an emerging technology. For the investor, an emerging technology is one that offers a relatively undiscovered method to solve a daunting wireless problem in a cost-effective way. The methods or technology itself may be non-conventional, but emerging technologies that become mainstream are typically more evolutionary than revolutionary. This is because a technology cannot succeed by itself – it must bring the whole sector with it. This paper presents an overview survey of emerging wireless technologies – 802.11n, 802.15.4 and 802.16. 802.11n is a recent extension of the popular 802.11a/b/g technology known as WiFi. UWB on the other hand is standardized as IEEE 802.15.4 for low power, low-data rate applications. This technology innovation called ZigBee will make it possible to remotely monitor various types of sensors-for air-conditioning, lighting, smoke alarms, and many more. "The next big thing" predicted in wireless access is the introduction of large Broadband Fixed Wireless Access cells using technologies such as WiMAX.

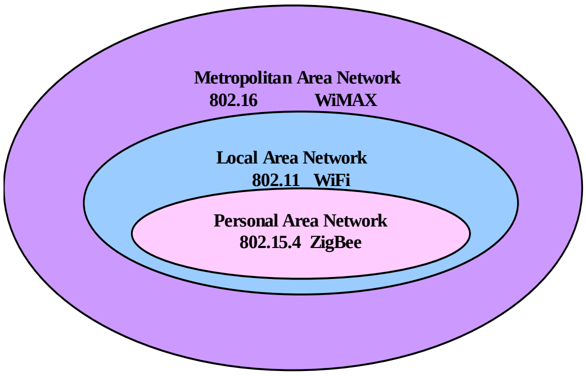

Fig. 1 Types of wireless access

In effect, most of these wireless technologies will not be islands in themselves, but will offer some interconnectivity between each other. All this will just help in creating a perfectly connected environment. So just think of it-the weather, temperature and other information is being communicated by tiny sensors based on ZigBee, passing data over radio waves from one to another. At the end of the line, the data is picked up by hotspots created by WiMAX or WiFi. All these innovations are not a shot in the dark. Work is happening on most of these technologies to bring out applications so that they really help everyone stay connected. Some of the technologies are already available, while others might be available towards the end of this year or the beginning of the next year. Various wireless network technology options are shown in Fig. 1. In the pages to follow, we will look at these wireless technologies and the applications they promise to make possible.

II. Wi-Fi (Wireless Fidelity) – 802.11n

Demand for wireless LAN hardware has experienced phenomenal growth during the past several years, evolving quickly from novelty into necessity. Wi-Fi technology is most commonly found in notebook computers and Internet access devices such as routers and DSL or cable modems. The growing pervasiveness of Wi-Fi is helping to extend the technology beyond the PC and into consumer electronics applications like Internet telephony, music streaming, gaming, and even photo viewing and in-home video transmission.

Manuscript received on November 30, 2006.
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These new uses, as well as the growing number of conventional WLAN users, increasingly combine to strain existing Wi-Fi networks. Fortunately, a solution is close at hand. The industry has come to an agreement on the components that will make up 802.11n, a new WLAN standard that promises both higher data rates and increased reliability. Though the specification is not expected to be finalized before end of 2007, the draft is proving to be reasonably stable as it progresses through the formal IEEE review process. [2]

A wireless LAN (WiFi) is a data transmission system designed to provide location-independent network access between computing devices by using radio waves rather than a cable infrastructure. Wi-Fi is meant to be used generically when referring to any type of 802.11 network, whether 802.11b, 802.11a, 802.11g etc. The first 802.11b networks could move data at up to 11 megabits per second (Mbps). Then came products using 802.11a, followed shortly thereafter by 802.11g, each with maximum speeds of 54Mbps and throughput of around 25Mbps. WLAN hardware built around 802.11g was quickly embraced by consumers and businesses seeking higher bandwidth. [1] The next Wi-Fi speed standard, 802.11n, will likely offer a bandwidth of around 108Mbps [2]. And because it will be an industry standard, n-compliant devices will be interoperable.

A. Characteristics of 802.11n

The emerging 802.11n specification differs from its predecessors in that it provides for a variety of optional modes and configurations that dictate different maximum raw data rates. This enables the standard to provide baseline performance parameters for all 802.11n devices, while allowing manufacturers to enhance or tune capabilities to accommodate different applications and price points. With every possible option enabled, 802.11n could offer raw data rates up to 600 Mbps. But WLAN hardware does not need to support every option to be compliant with the standard. In the current year, for example, most draft-n WLAN hardware available is expected to support raw data rates up to 300 Mbps [1]. In comparison, every 802.11b-compliant product support data rates up to 11 Mbps, and all 802.11a and 802.11g hardware support data rates up to 54 Mbps.

1) Better OFDM

In the 802.11n draft, the first requirement is to support an OFDM implementation that improves upon the one employed in the 802.11a/g standards, using a higher maximum code rate and slightly wider bandwidth. This change improves the highest attainable raw data rate to 65 Mbps from 54 Mbps in the existing standards [2].

2) MIMO Improves Performance

One of the most widely known components of the draft specification is known as Multiple Input Multiple Output, or MIMO [2]. MIMO exploits a radio-wave phenomenon called multipath: transmitted information bounces off walls, doors, and other objects, reaching the receiving antenna multiple times via different routes and at slightly different times. Uncontrolled, multipath distorts the original signal, making it more difficult to decipher and degrading Wi-Fi performance. MIMO harnesses multipath with a technique known as space-division multiplexing. The transmitting WLAN device actually splits a data stream into multiple parts, called spatial streams, and transmits each spatial stream through separate antennas to corresponding antennas on the receiving end. The current 802.11n draft provides for up to four spatial streams, even though compliant hardware is not required to support that many [2]. Doubling the number of spatial streams from one to two effectively doubles the raw data rate. There are trade-offs, however, such as increased power consumption and, to a lesser extent, cost. The draft-n specification includes a MIMO power-save mode, which mitigates power consumption by using multiple paths only when communication would benefit from the additional performance. The MIMO power save mode is a required feature in the draft-n specification.

3) Improved Throughput and Higher Data Rates

Another optional mode in the 802.11n draft effectively doubles data rates by doubling the width of a WLAN communications channel from 20 MHz to 40 MHz. The primary trade-off here is fewer channels available for other devices. In the case of the 2.4-GHz band, there is enough room for three non-overlapping 20-MHz channels. Needless to say, a 40-MHz channel does not leave much room for other devices to join the network or transmit in the same airspace. This means intelligent, dynamic management is critical to ensuring that the 40-MHz channel option improves overall WLAN performance by balancing the high-bandwidth demands of some clients with the needs of other clients to remain connected to the network.

TABLE I
MAJOR COMPONENTS OF DRAFT 802.11N [1]

Feature	Definition
Better OFDM	Supports wider bandwidth & higher code rate to bring maximum data rate to 65 Mbps
Space-Division Multiplexing	Improves performance by parsing data into multiple streams transmitted through multiple antennas.
Diversity	Exploits the existence of multiple antennas to improve range and reliability. Typically employed when the number of antennas on the receiving end is higher than the number of streams being transmitted.
MIMO Power Save	Limits power consumption penalty of MIMO by utilizing multiple antennas only on as-needed basis.
40 MHz channels	Effectively doubles data rates by doubling channel width from 20 MHz to 40MHz.
Aggregation	Improves efficiency by allowing transmission bursts of multiple data packets between overhead communications.
Reduced Inter-frame Spacing (RIFS)	One of several draft-n features designed to improve efficiency. Provides a shorter delay between OFDM transmissions than in 802.11a or g.
Greenfield Mode	Improves efficiency by eliminating support for 802.11a/b/g devices in an all draft-n network.

TABLE II
COMPARISON OF THE PRIMARY IEEE 802.11 SPECIFICATIONS

	802.11a	802.11b	802.11g	802.11n
Standard Approved	July 1999	July 1999	June 2003	Not yet ratified
Maximum Data Rate	54 Mbps	11Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS or CCK	DSSS or CCK or OFDM	DSSS or CCK or OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
Number of Spatial Streams	1	1	1	1,2,3, or 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

B. Applications of 802.11n

Because it promises far greater bandwidth, better range, and reliability, 802.11n is advantageous in a variety of network configurations. And as emerging networked applications take hold in the home, a growing number of consumers will come to view 802.11n not just as an enhancement to their existing network, but also as a necessity. Some of the current and emerging applications that are driving the need for 802.11n are listed below:

- ***Voice over IP (VoIP):*** VoIP is mushrooming as consumers and businesses alike realize they can save money on long-distance phone calls by using the Internet instead of traditional phone service. An increasingly popular way to make Internet calls is with VoIP phones, which are battery-powered handsets that typically connect to the Internet with built-in 802.11b or 802.11g. Telephony does not demand high bandwidth, although it does require a reliable network connection to be usable. Both 802.11b and 802.11g consume less power than 802.11n in MIMO modes, but single-stream 802.11n may become prevalent in VoIP phones. VoIP phones can benefit today from the increased range and reliability of a draft-n access point.
- **Streaming video and music:** As with voice, streaming music is an application that requires a highly reliable connection that can reach throughout the home. Millions of consumers are building libraries of digital music on their personal computers by ripping their CD collections and buying digital recordings over the Internet. In addition, growing numbers are streaming music directly from the Internet. Though higher bandwidth is not absolutely necessary, the additional range and reliability that draft-n offers may be better suited to streaming music than older-generation WLAN hardware.
- **Gaming:** Gaming is an application that increasingly is making use of home WLANs, whether users connect wirelessly to the Internet from their computers and portable gaming devices or use the network to compete with others in the home.
- **Network attached storage:** A growing application that demands all that 802.11n has to offer high data rates as well as range and reliability is Network-Attached Storage, or NAS. NAS has become popular in the enterprise as an inexpensive, easy-to-install alternative for data backup. More recently, NAS is taking hold in small offices and even some homes, as users want to safeguard their growing digital photo albums from hard drive failure, and as the price of self-contained NAS backup systems falls well below $1,000. New, more exciting applications for NAS are emerging, such as video storage centers that demand reliable, high-bandwidth connections to stream prerecorded TV shows, music videos and full-length feature films to televisions and computers throughout the house.
- **Transferring large files** such as prerecorded TV shows from a personal video recorder onto a notebook computer or portable media player for viewing outside the home takes planning and patience on an older WLAN. Fig 2 compares the time it would take to transfer a 30-minute video file. At the best data transfer rate, it would take 42 minutes to copy the file using 802.11b, and less than a minute with a two-antenna draft-n client.

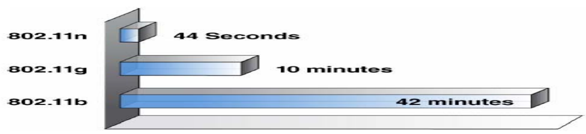

Fig. 2 Time (Best Case) to Transfer 30-Minute Video

III. ZIGBEE – 802.15.4

ZigBee is one of the newest technologies enabling Wireless Personal Area Networks (WPAN). ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard. The technology is intended to be simpler and cheaper than other WPANs such as Bluetooth. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption. Though WPAN implies a reach of only a few meters, 30 feet in the case of ZigBee, the network will have several layers, so designed as to enable intrapersonal communication within the network, connection to a network of higher level and ultimately an uplink to the Web.

Importance of Zigbee

There are a multitude of standards that address mid to high data rates for voice, PC LANs, video, etc. However, up till now there hasn't been a wireless network standard that meets the unique needs of sensors and control devices. Sensors and controls don't need high bandwidth but they do need low latency and very low energy consumption for long battery lives and for large device arrays. There are a multitude of proprietary wireless systems manufactured today to solve a multitude of problems that also don't require high data rates but do require low cost and very low current drain.

The ZigBee Alliance is not pushing a technology; rather it is providing a standardized base set of solutions for sensor and control systems. To allow vendors to supply the lowest possible cost devices the IEEE standard defines two types of devices: full function devices (FFD) and reduced function devices (RFD) [4]. An IEEE 802.15.4/ZigBee network requires at least one full function device as a network coordinator, but endpoint devices may be reduced functionality devices to reduce system cost.

The ZigBee Standard has evolved standardized sets of solutions, called **'layers'**. [4] These layers facilitate the features that make ZigBee very attractive: low cost, easy implementation, reliable data transfer, short-range operations, very low power consumption and adequate security features.

Network and Application Support layer: The network layer has been designed to allow the network to spatially grow without requiring high power transmitters. The network layer also can handle large amounts of nodes with relatively low latencies. The APS sub-layer's responsibilities include maintenance of tables that enable matching between two devices and communication among them, and also discovery, the aspect that identifies other devices that operate in the operating space of any device.

Physical layer: The IEEE 802.15.4 physical layer accommodates high levels of integration by using direct sequence to permit simplicity in the analog circuitry and enable cheaper implementations.

Media access control layer: The IEEE 802.15.4 media access control layer permits use of several topologies without introducing complexity and is meant to work with large numbers of devices.

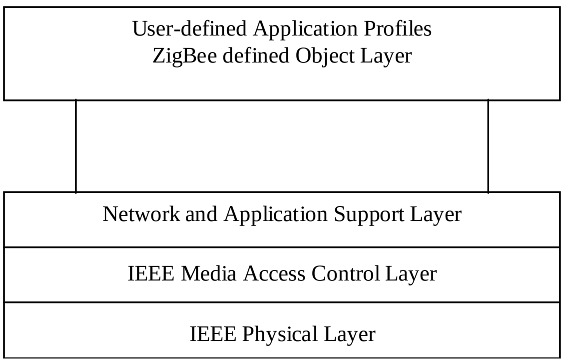

Fig. 3 IEEE 802.15.4 / ZigBee Stack Architecture

A. Characteristics of ZigBee

ZigBee is poised to become the global control/sensor network standard. It has been designed to provide the following features: [3]

1) Low power consumption, with battery life ranging from months to years.
2) Maximum data rates allowed for each of the frequency bands are fixed as 250 kbps @2.4 GHz, 40 kbps @ 915 MHz, and 20 kbps @868 MHz.
3) High throughput and low latency for low duty-cycle applications (<0.1%).
4) Channel access using Carrier Sense Multiple Access with Collision Avoidance (CSMA - CA).
5) Addressing space of up to 64 bit IEEE address devices, 65,535 networks.
6) 70-100m range.
7) Low cost (device, installation, maintenance). Low cost to the users means low device cost, low installation cost and low maintenance. ZigBee devices allow batteries to last up to years using primary cells (low cost) without any chargers (low cost and easy installation). ZigBee's simplicity allows for inherent configuration and redundancy of network devices provides low maintenance.
8) High density of nodes per network: ZigBee's use of the IEEE 802.15.4 PHY and MAC allows networks to handle any number of devices. This attribute is critical for massive sensor arrays and control networks.
9) Fully reliable "hand-shaked" data transfer protocol.
10) Different topologies like: star, peer-to-peer, mesh

B. Applications of ZigBee

ZigBee networks consist of multiple traffic types with their own unique characteristics, including periodic data, intermittent data, and repetitive low latency data. The characteristics of each are as follows:

- Periodic data – usually defined by the application such as a wireless sensor or meter. Data typically is handled using a beaconing system whereby the sensor wakes up at a set time and checks for the beacon, exchanges data, and goes to sleep.
- Intermittent data – either application or external stimulus defined such as a wireless light switch. Data can be handled in a beaconless system or disconnected. In disconnected operation, the device will only attach to the network when communications is required, saving significant energy.
- Repetitive low latency data – uses time slot allocations such as a security system. These applications may use the guaranteed time slot (GTS) capability. GTS is a method of QoS that allows each device a specific duration of time as defined by the PAN coordinator in the Superframe to do whatever it requires without contention or latency.

For example, an automatic meter reading application represents a periodic data traffic type with data from water or gas meters being transmitted to a line powered electric meter and passed over a powerline to a central location. Using the beaconing feature of the IEEE standard, the respective Reduced Function Device (RFD) meter wakes up and listens for the beacon from the PAN coordinator, if received, the RFD requests to join the network. The PAN coordinator accepts the request. Once connected, the device passes the meter information and goes to sleep. This capability provides for very low duty cycles and enables multi-year battery life. Intermittent traffic types, such as wireless light switches, connect to the network when needed to communicate (i.e. turn on a light). For repetitive low latency applications a guaranteed time slot option provides for Quality of Service with a contention free, dedicated time slot in each super frame that reduces contention and latency. Applications requiring timeliness and critical data passage may include medical alerts and security systems. In all applications, the smaller packet sizes of ZigBee devices results in higher effective throughput values compared to other standards. ZigBee networks are primarily intended for low duty cycle sensor networks (<1%). A new network node may be recognized and associated in about 30 ms. Waking up a sleeping node takes about 15 ms, as does accessing a channel and transmitting data. ZigBee applications benefit from the ability to quickly attach information, detach, and go to deep sleep, which results in low power consumption and extended battery life.

C. Comparison of ZigBee and Bluetooth

The bandwidth of Bluetooth is 1 Mbps; ZigBee's is one-fourth of this value. The strength of Bluetooth lies in its ability to allow interoperability and replacement of cables, ZigBee's, of course, is low costs and long battery life.

Most important in any meaningful comparison are the diverse application areas of all the different wireless technologies. Bluetooth is meant for such target areas as wireless USB's, handsets and headsets, whereas ZigBee is meant to cater to the sensors and remote controls market and other battery operated products.

In a gist, it may be said that they are neither complementary standards nor competitors, but just essential standards for different targeted applications. The earlier Bluetooth targets interfaces between PDA and other device (mobile phone / printer etc.) and cordless audio applications. Bluetooth has addressed a voice application by embodying a fast frequency hopping system with a master slave protocol. ZigBee has addressed sensors, controls, and other short message applications by embodying a direct sequence system with a star or peer-to-peer protocols.

IV. WiMAX (Worldwide Interoperability for Microwave Access) – 802.16

Yet another wireless network technology may have an impact over the next few years: 802.16, better known as **WiMAX**. The IEEE approved the 802.16 standards in June 2004 [5]. This technology supports speeds as high as 70Mbps and a range of up to 48 kilometers. WiMAX can be used for wireless networking like the popular WiFi. WiMAX allows higher data rates over longer distances, efficient use of bandwidth, and avoids interference almost to a minimum. WiMAX can be termed partially a successor to the Wi-Fi protocol. Current technologists envision a WiMAX receiver in a person's home, with a WiFi transmitter to serve in-home connections, and longer term having laptops and personal devices capable of transmitting directly to WiMAX towers.

WiMAX also makes ubiquitous Internet access possible. WiMAX, operating at comparable distances as cellular phones, can be installed on cellular towers and allow Internet data access in as many places as cellular phone access. This adds a new dimension to what Internet access providers can offer: a broadband connection that a person can take with them when they travel.

WiMAX Forum was formed in April 2001, to promote conformance and interoperability of the standard IEEE 802.16. The forum was formed solely for development & promotion of devices supported by the 802.16 standard. In September 2004, Intel introduced initial samples of a WiMAX chipset, named Rosedale. Intel has plans to ship WiMAX devices for use in the office and home by 2007. [5]

The IEEE 802.16 standard is versatile enough to accommodate time division multiplexing (TDM) or frequency division duplexing (FDD) deployments and also allows for both full and half-duplex terminals. WiMAX uses microwave radio technology to connect computers to the Internet. WiMAX works very much like cell phone technology in that reasonable proximity to a base station is required to establish a data link to the Internet. Users within 3 to 5 miles of the base station will be able to establish a link using non line- of-sight (NLOS) technology with data rates as high as 75Mbps. Users up to 30 miles away from the base station with an antenna mounted for line-of-sight (LOS) to the base station will be able to connect at data rates approaching 280Mbps [6].

A. Characteristics of WiMAX

Technical aspects of 802.16a that are instrumental in powering robust performance include following characteristics:

- Power: Varies with band. Profiles from 100 Mw up to 2W
- Configuration: P-P and P-MP Cellular
- Spectrum: Initially 3.5 GHz licensed and 5.8 GHz unlicensed bands
- Radio interface: OFDM, using 256 tones
- Access Protocols: Downstream - TDM (Broadcast), Upstream - TDMA with access contention
- Security via station authentication and encryption
- Data rates variable with channel bandwidth 3.5 MHz in 3.5 GHz band, 20 MHz in 5.8 GHz band
- Actual realizable data rates are ~ 2b/Hz
- Maximum range ~2Km for indoor Non-LOS cellular service at 3.5 GHz

B. Applications of WiMAX

WiMAX will allow people to go from their homes to their cars, and then travel to their offices or anywhere in the world, all seamlessly. [7] WiMAX can serve the business, residential and mobile segments. The applications in these areas are listed below:

Residential users

- Basic voice services, low cost domestic & international calls
- Basic (dialup speed) to advanced (over 1Mbps) data connections

•Bundled voice and data services

Business users

- Basic data connectivity for small businesses
- Advanced data services to medium and large businesses
- Feature-rich, low cost voice services (VoIP)

Mobile users (mobile WiMAX only)

- Data connectivity for mobile workforce
- Data connectivity for international visitors

V. Comparison of Wireless Technologies

The use of wireless technologies is beginning to appear similar to the initial development of the railways. Each technology seems to have a different "gauge" and compatibility issues seem to confuse the novice. The main points of comparison of the three technologies that have been discussed in this paper are listed in table III.

TABLE III
Comparison of Emerging Wireless Technologies

Technology	**WiFi - 802.11n**	**ZigBee**	**WiMAX**
Application	Wireless LAN, Internet	Sensor Networks	Metro Area Broadband Internet connectivity
Typical Range	100m	70-100m	50 km
Frequency Range	2.4 GHz	2.4GHz	2-11GHz
Data Rate	108 - 600Mbps	250Kbps	75Mbps
Modulation	DSSS	DSSS	QAM
Network	IP & P2P	Mesh	IP
IT Network Connectivity	Yes	No	Yes
Network Topology	Infrastructure (Ad-hoc also possible)	Ad-hoc	Infrastructure
Access Protocol	CSMA/CA	CSMA/CA	Request/Grant
Key Attributes	Wider Bandwidth, Flexibility	Cost, Power	Throughput, Coverage

VI. Conclusion

This paper has presented an overview of emerging wireless technologies. 802.11n is viewed as the most likely contender for the home network backbone. ZigBee, on the other hand, is likely to make best use of its low-power and high-speed operation in short-range equipment interconnects, such as personal computers and portable equipment. ZigBee networks are primarily intended for low duty cycle sensor networks (<1%). 802.11n is viewed as being superior in maintaining compatibility with existing wireless LAN, while ZigBee is generally thought more likely to achieve lower levels of power consumption. Our vision of the future is that WiMAX will enable mobile broadband at an affordable price. This will be achieved through the adoption of WiMAX by a cellular provider seeking to make a jump to this disruptive technology. WiMAX is not expected to completely eliminate the Wi-Fi technology in the near future, but will be a complement to Wi-Fi as its primary backhaul service of choice. WiMAX promises to help corporations expand business, drive down costs, increase overall profitability, increase the quality of service, and increase the number of users that connect to the Internet.

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