Wireless IPTV over WiMAX: Challenges and Applications

Francis E. Retnasothie*, M. Kemal Özdemir*, Tevfik Yücek‡†, Hasari Celebi‡†, Joseph Zhang*, and Ranesh Muththaiah*
* Logus Broadband Wireless Solutions
845 Progress Ave, Toronto, Canada M1H 2X4
† Logus Broadband Wireless Solutions USA
3803 Corporex Park Plaza Suite 700, Tampa, FL 33619
‡University of South Florida, Department of Electrical Engineering
4202 E. Fowler Avenue, Tampa, FL, 33613
E-mail: {francis, kemal, tevfik, hasari, joseph, ranesh}@loguswireless.com

***Abstract*— Internet Protocol Television (IPTV) is gaining recognition as a viable alternative for the delivery of video by telecommunications and cable companies. It features bandwidth efficiencies, and management; therefore, it is ideally suited for broadcast, multicast, unicast interactive and multimedia services (IMS - IP multimedia). Core networks are packet-based, however, access networks are not always packet-based. Furthermore, they are wired as either fiber-coax or fiber-twisted pair topologies. Design, construction, and maintenance costs of such topologies are exorbitant, making the IPTV deployment economically unviable, especially in underdeveloped countries and rural areas. Worldwide Interoperability for Microwave Access (WiMAX) offers a wireless solution in the access networks that can support IPTV services. WiMAX is capable of very high data rates, longer reach, and operates in non-line of sight (NLOS) modes in licensed and license exempt frequencies. Bandwidth is scalable and managed. Contents are encrypted for secured transmission and mobility is supported at vehicular speeds. Installation and maintenance costs of WiMAX systems are at a fraction of the costs of wired access networks. Taking advantage of these features, IPTV services can be designed, delivered, and managed cost effectively without compromising the video and audio quality. In this paper, we present IPTV over WiMAX implementation in such scenarios. We identify challenges and discuss ways to overcome them, especially those in medium access control (MAC), Physical Layer (PHY) and radio sub-systems. Despite of these challenges, it is observed that IPTV over WiMAX is very feasible.**

I. Introduction

Internet Protocol Television (IPTV) has been becoming popular as it promises to deliver the content to users whenever they want. The next step is to deliver this content wherever the users are. Traditional wire-based access networks can deliver the contents only to the fixed points. Hence, a new technology that can deliver the content to mobile users is needed.

Worldwide Interoperability for Microwave Access (WiMAX) technology is based on IEEE $802.16-2004$ and $802.16e-2005$ standards for fixed and mobile wireless access in metropolitan area networks (MAN) [1], [2]. It can deliver data rates of 70Mbps, cover ranges in excess of 30km, and it can provide secure delivery of content and support mobile users at vehicular speeds.

WiMAX medium access control (MAC) layer supports real time poling services (rtPS) that ensures required bandwidth and minimum latencies for video services through quality of service (QoS). It uses orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) physical layer (PHY) that are resilient to multipath fading channels. Moreover, it uses adaptive modulation schemes and forward error correction (FEC) to increase service quality. Since WiMAX PHY supports varying frame sizes and scalable bandwidth, WiMAX is an ideal choice for IPTV applications.

WiMAX is considered as an all IP access network and offers transparency for packet based core networks. Additionally, WiMAX radios are designed not to add any impairment to the content delivery. Hence, WiMAX base stations (BSs), subscriber and mobile stations (SSs/MSs) are ideally suited for the delivery of IP based services; (triple play) VoIP, IPTV, internet multimedia over wireless MAN. This makes WiMAX a superior choice over conventional cable, DSL, and satellite solutions. WiMAX access networks will offer the much desired ubiquity for the content. Eventually, WiMAX deployments will deliver IPTV to rural and underserved regions with high degree of video and audio quality at affordable prices.

In this paper, we present a system deployment model for IPTV services over WiMAX. More specifically, the challenges encountered on IPTV implementation over WiMAX are discussed. These include the challenges in MAC, PHY layer, radio transceiver design and implementation. Despite these challenges, IPTV over WiMAX is feasible and it is a viable alternative to the cable and DSL for IPTV services. The paper is organized as follows: first the system model will be given in Section II. Then, the proposed implementation with details of MAC, PHY and radio transceiver are described in Section III. In Section IV, we discuss applications and challenges. Finally, the paper is concluded by Section V.

II. System Model

Functional block diagram of an IPTV application is illustrated in Fig. 1. Video servers/encoders store audio/video (A/V) content which are encoded and compressed from live and pre-recorded programs. Video servers/encoders are either centralized or distributed in core networks.

Fig. 2 shows the protocol stack for IPTV transmission. A/V content from the source is formatted, compressed (mostly using MPEG-2 encoding and compression standard) and is encapsulated as real time transport protocol (RTP). This payload is transported as either user datagram protocol (UDP) or

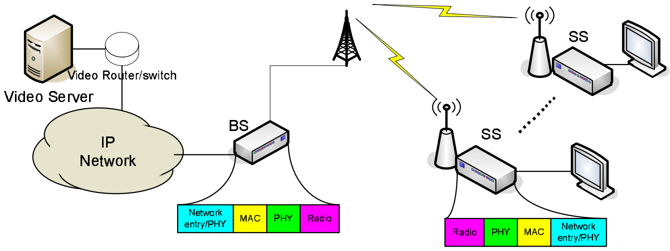

Fig. 1. System model for IPTV applications.

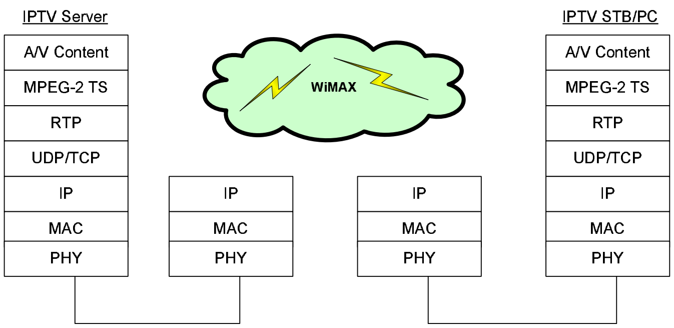

Fig. 2. Protocol Stack for IPTV Transmission.

transmission control protocol (TCP) datagram which in turn becomes the payload for internet protocol (IP). The IP payload is encapsulated as Ethernet 802.3 and 10/100/1G Bass-T traffic that travels over the core networks. WiMAX BS that sits at the edge of the core network receives the 802.3 packets and the BS MAC decapsulates Ethernet headers and encapsulates the IP payload as 802.16 MAC PDUs and then into PHY PDUs. The 802.16 PHY prepares these PDUs for wireless air-link by performing FEC, symbol mapping and OFDM modulation. The radio transceiver radiates these signals through antennas to SSs and MSs within the cell. The reversed process through said layers delivers A/V content to IPTV ready STB, PCs.

One of the drawbacks of ”packet” based transmission is the overheads associated with each layer. As a result, the payload capacity is greatly reduced. IPTV transmission requires higher payload capacity, therefore, it poses a challenge in providing maximum service. The user datagram protocol (UDP), transmission control protocol (TCP) and internet protocol (IP) with associated overheads are part of WiMAX payload and considered out of scope of this paper. Note that IEEE 802.16 MAC and PHY adds its own overheads. We will discus them and provide recommendations for the reduction of aforementioned overheads.

III. Proposed IPTV Implementation

WiMAX MAC, PHY, and Radio transceivers are organized into logical sub sections for efficient delivery of IP based payload including voice, video, multimedia and Internet over wireless. These are described below in their respective sections.

Logus ”Beaver” (WiMAX BS) in association with the ”Loon” (WiMAX SS) provide a point to multipoint (PtMP) delivery system for IPTV applications and conforms to the IEEE and WiMAX standards and certification. The payload can be either standard definition (SDTV) or high definition (HDTV). For real time streaming video services, UDP ports can be used and for video on demand (VoD), TCP ports can be used. Broadcast, multicast or unicast services are also supported. As a result, there can be multiple packets from various sources that must be delivered to targeted users with different QoS parameters making it a challenging task. WiMAX BS MAC addresses this issue through effective scheduling of services. For this reason, it is expected that MAC scheduling and implementation will be a key differentiator amongst competitors products.

A. Medium Access Control (MAC) Layer

The IEEE 802.16 MAC is logically divided into three sublayers. These are convergence sublayer (CS), common part sublayer (CPS) and security sublayer (SS). In the convergence sublayer, IPTV packets over Ethernet are received from the network as MAC SDUs. Received packets are then classified based on their TCP/UDP port, source/destination, IP, MAC address etc. Each packet is then assigned to a connection for transmission over the air. In the common part sublayer, packets are fragmented and/or packed for the efficient use of available bandwidth. Fragmentation also enables automatic request (ARQ) services to minimize retransmission. MAC PDUs are constructed in this sublayer. Packets are scheduled based on service level agreements (SLA) and quality of service (QoS) requirements for both DL and UL. Ultimately, the frame in which IPTV packets will be transmitted is prepared in this layer. In the security sublayer, packets are encoded to prevent theft of service. Key exchanges between SSs and for secure authenticated transmission, the use of cyclic redundancy check (CRC) are also implemented in this sublayer.

Negotiations for network entry, initial/periodic ranging, and capabilities are performed at the CPS to establish and maintain connections between the BS and SSs/MSs. Identification of air link quality, bandwidth grants, and security parameters are also performed in the CPS using MAC management messages.

B. MAC scheduler for IPTV Applications

The 802.16 MAC is connection-oriented. The BS assigns connections with unique IDs (CIDs) to each UL and DL transmission. At the CS layer, the classifier maps traffic flows to connections with distinct scheduling services. Hence, it is anticipated that multiple schedulers will be implemented to address varying demands of users. Obviously, this puts another degree of burden on the MAC implementation. Fig. 3 shows the proposed implementation of the MAC scheduler. The mechanism includes service flow QoS scheduling, dynamic service establishment, and the two-phase activation model. Scheduling services represent the data handling mechanisms supported by the MAC scheduler for data transport on a connection. Packet Classifier block will send the packet header’s information to Connection Control component. Based on the header’s information, Connection Control assigns CID and service flow ID (SFID) to the corresponding packet or flow. Each SFID will be related to a set of QoS parameters stored in QoS Policy component.

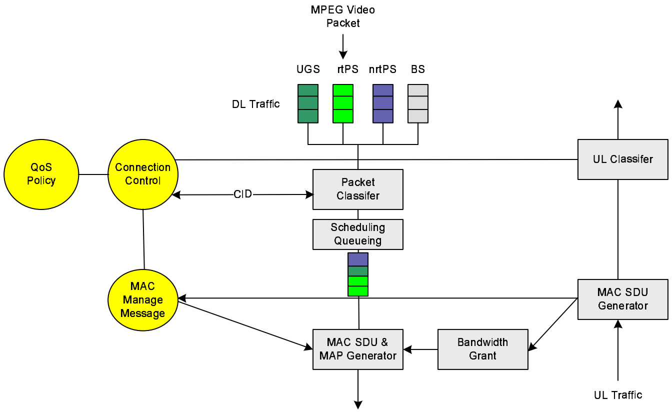

Fig. 3. MAC QoS architecture.

For the IPTV services, the mandatory QoS service flow parameters are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Maximum Latency, and Request/Transmission Policy. Either BS or SS can initiate the creation of service flows. MAC management component handles dynamic service access/change (DSA/DSC)'s transaction and dynamically change QoS parameters. A successful DSC transaction changes a service flow's QoS parameters by replacing both the Admitted and Active QoS parameter sets.

The two-phase model performs the functions that include: conserving network resources until a complete end-to-end connection has been established, performing policy checks and admission control on resources as quickly as possible, and preventing several potential theft-of-service scenarios.

Based on the assigned QoS parameters and settings, Scheduling and Queuing block and MAP Generator block perform the function to reserve the resource in data path. The source of the IPTV packets plays an important role in the QoS strategy for IPTV applications. Broadcast IPTV packets are in general unpaid services, while unicast IPTV packets are paid services. Hence the delivery of unicast packets is more critical than the broadcast packets, requiring different QoS parameters.

C. MAC-PHY Interface

PHY PDUs (packets) are transmitted from MAC to PHY using SPI3 standards interface. We use our own primitives based protocol to ensure the seamless transfer without packet loss over this interface.

D. Physical Layer (PHY)

Our PHY is designed and implemented on a Xilinx FPGA. Xilinx Virtex-4 [3] is chosen for its resource capabilities and optimized IP (proprietary) blocks (i.e. Viterbi decoder) as specified by IEEE $802.16d$ standard. The PHY supports BPSK, QPSK, QAM16, and QAM64 modulation types with different coding rates. Adaptive modulation and coding capability is used to provide better quality video to the served subscriber stations. Optimal coding rate is used for each modulation type to achieve smaller bandwidth without compromising quality.

Fig. 4 shows the block diagram of our PHY implementation. Both transmitter and receiver blocks are shown. In the transmitter path, channel coding is applied to the video data in order to protect the video content from channel errors and hence guarantee the delivery of high quality IPTV packets. The data from the MAC layer is first randomized to remove the correlation between the information bits. The FEC block consists of the concatenation of a Reed Solomon (RS) outer code and a convolutional inner coding. Support of block turbo coding (BTC) and convolutional turbo coding (CTC) is left optional in the standard and hence not implemented in our current design. The encoding is performed by first passing the data in block format through the RS encoder and then passing it through a zero-terminating convolutional encoder. Different coding rates may be obtained for convolutional coding by puncturing the base rate. All encoded data bits are interleaved by a block interleaver with a block size corresponding to the number of coded bits per the allocated subchannels per OFDM symbol. After bit interleaving, the data bits are fed serially to the constellation mapper whose output is taken into time domain using IFFT block. After addition of preamble and cyclic prefix (CP), the signal is passed to Radio for transmission using PHY-Radio interface. The receiver path of

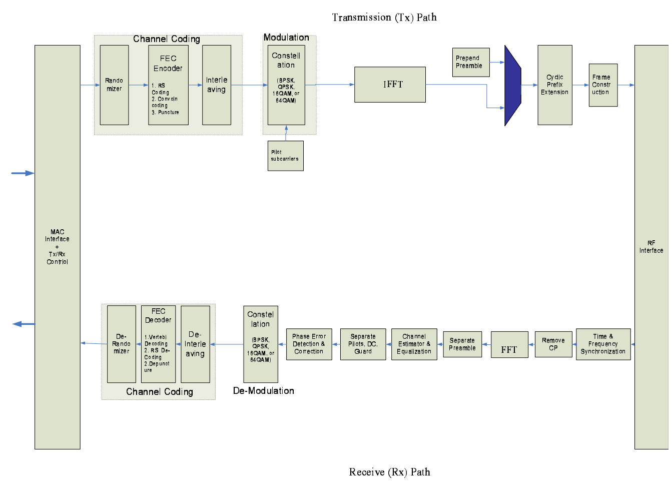

Fig. 4. OFDM based PHY layer blocks.

the PHY includes dual operations of the transmitter along receiver specific blocks. These include channel estimation, equalization, phase tracker, soft decoding, and time/frequency synchronization. Note that the receiver specific blocks are vendor specific and are not mandated by neither IEEE nor WiMAX forum. Furthermore, these algorithms are unique to each vendor, and hence these are the blocks where uniqueness to the product could be introduced. While evaluating the performance of the receiver algorithms, signal to noise ratio (SNR), error vector magnitude (EVM) or bit error rate (BER) can be used as criteria.

The OFDM PHY supports frame-based transmission. A frame consists of a downlink subframe and an uplink subframe. A downlink subframe is composed of only one downlink PHY PDU. An uplink subframe consists of contention intervals scheduled for initial ranging and bandwidth request purposes and one or multiple uplink PHY PDUs, each transmitted from a different SS. Since video transport is asymmetric, more DL bandwidth can be allocated for the users. Hence, better bandwidth utilization can be obtained.

E. PHY-Radio Interface

The main responsibility of the PHY-Radio interface is to manage the data communication between the MAC control paramters and the radio. Furthermore, the MAC layer configures and controls the programmable radio devices through this interface.

F. Radio Transceiver

The block diagram for the WiMAX BS transceiver is given in Fig. 5. The radio transceiver consists of digital and analog devices. This structure is flexible in the sense that the fundamental parameters of the radio, such as the center frequency and transmit power levels, can be changed through the software.

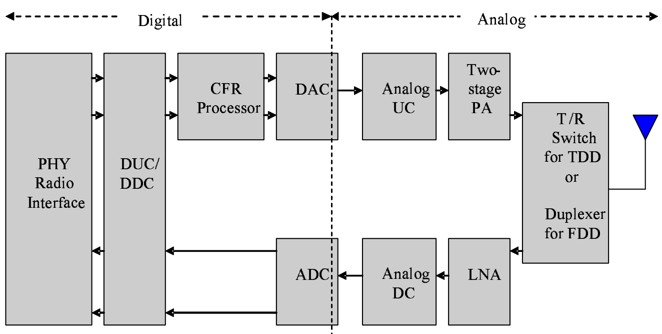

Fig. 5. Block diagram of WiMAX BS Radio Transceiver.

On the transmitter side, the digital signal, in the form of in-phase (I) and quadrature (Q) samples, is handed over to the wideband digital upconverter (DUC)/ digital downconverter (DDC) device. At the stage of the DUC, the transmit signal can be filtered and interpolated. The resultant transmit signal is sent to the crest factor reduction (CFR) processor, where the peak-to-average-power-ratio (PAPR) of the transmit signal is adjusted. The clipped transmit signal is then passed to the digital-to-analog converter (DAC) to convert the digital signal into the corresponding analog form. The center frequency of the first intermediate-frequency (IF) stage is determined by the DAC since it embeds digital coarse and fine mixers. The analog signal is upconverted to a second IF stage and then to the final radio frequency (RF) stage by employing two-stage analog upconverter (UC). In order to provide large coverage, the RF signal is amplified through two-stage power amplifier (PA). The amplified signal is passed to the antenna through the duplexing device (i.e. transmitter/receiver (T/R) switch for the TDD radio).

On the receiver side, the received signal is amplified using a low noise amplifier (LNA). The signal at the output of the LNA is downconverted to the final IF stage using the two-stage downconverter (DC). The analog signal is digitized and I/Q samples are generated at the output of the analog-to-digital converter (ADC). The I/Q samples are filtered and decimated and then sent to the PHY-Radio interface for further post-processing. The radio design challenges associated with the implementation of wireless IPTV over WiMAX are discussed in the following section.

IV. Applications and Challenges

WiMAX provides a wide spectrum of applications in a multitude of environments. VoIP, Video over IP (IPTV), Internet, IP multimedia (IMS) are some of the services that can be provided to areas where access networks do not exist at this time for a fraction of cost. One of such applications, IPTV over WiMAX, is the focus of this paper. We will expand on this application in this section. Since applications and challenges related to MAC layer are discussed in the previous section, mainly the applications and challenges related to the radio transceiver are emphasized in this section.

One of the great features of the WiMAX is its inherent multicast capability. Multicast is a bandwidth-conserving technology that allows a BS to send packets (video in this case) to a subset of all SSs as a group transmission. The number of available TV stations is limited and there might be a large group of users that would like to tune to the same TV station. For example, during a Super Bowl game, a huge usage is expected. However, most of the users will want to tune to a specific channel. Using the multicast feature of WiMAX, all of these users can be served consuming a relatively very small bandwidth. This idea can be extended to any TV channel as there expected to be more than a single user viewing any TV show.

The fact that Mobile WiMAX supports communication at vehicular speeds is another great feature of WiMAX. The users have the capability to reach multimedia information even when they are traveling or outside of their homes which is not possible with cable TV.

As discussed in the system model section, packet based transmission has significant amount of overhead and is compounded from layer to layer. This reduces the effective payload capacity. IPTV, which requires high capacity, is impacted by these overheads. While UDP and/or TCP headers and IP headers remain within the payload and cannot be accessed within a WiMAX system, the overhead created by the WiMAX can be reduced significantly by using payload header suppression (PHS) and robust header compression (ROHC).

WiMAX systems requires high performance radio transceivers. The main features of WiMAX radio transceivers are high dynamic range, low phase noise, high stability, low noise and high linearity [2], [4]. Designing a high performance transceiver is a challenging task [5], especially for the IPTV applications. For instance, IPTV applications require higher bandwidth relative to the other multimedia applications such as voice and data, which introduces additional challenges. The main performance parameters of radio transceiver to support IPTV services are high dynamic range, low phase noise, high stability, low noise, high linearity, (relatively) high bandwidth, and low image rejection, which are discussed in the sequel.

The devices that are employed throughout the transceiver have excellent spurious free dynamic range capability (SFDR), which is a crucial parameter in IPTV applications. For instance, the ADC and DAC provide typically 86dBc and 78dBc, respectively. Furthermore, the phase noise is another important characteristic of the radio transceiver that can affect the quality of the IPTV services. The typical phase noise requirement for WiMAX transceivers is less than -100dBc/Hz at 100kHz. This requirement is achieved in the proposed radio transceiver structure by employing high performance clock distribution circuitry along with the dual VCO/PLL synthesizers. Note that since double-stage conversion approach is used in the proposed radio transceiver, both transmit and receive sides have their own dual VCO/PLL synthesizers. The reference clock that satisfies the above phase noise requirement is supplied to the frequency synthesizers from highly stable temperature compensated crystal oscillator (TCXO) through the configurable clock distribution circuitry. The reference oscillators used in the proposed radio structure maintains frequency tolerance of less than 8ppm over 10 years, which is mandated by the standard.

Low noise is another important performance criterion to achieve high-quality IPTV services. The components throughout the transmit and receive chains contribute to the composite noise. However, the components used in the proposed structure have high signal-to-noise-ratio (SNR) capability. The ADC provides SNR level of 72dB FS typically. Moreover, software tunable attenuators and filters are distributed throughout the transmit and receive chain to control and suppress the noise level.

Two cascaded highly linear power amplifiers (PAs), which provide maximum $+36$dBm composite transmit power level, are used to support long-distance communications. These PAs along with the Crest Factor Reduction (CFR) processor, which is based on idea of power back-off technique, are employed to maintain superior linearity.

The proposed radio structure has a capability to support high bandwidth transmission and reception up to 70MHz. Furthermore, low latency is another main requirement of the IPTV applications, which current design has.

Out-of-band rejection is an important performance parameter in mobile radios, especially for the IPTV services. For instance, interference to the other IPTV channels is minimized by realization of minimum 60dB image rejection requirement mandated by the standard. In the proposed radio structure, this requirement is achieved by suppressing harmonics using two-stage up/down conversion as well as high performance surface acoustic wave (SAW) filters. Moreover, the image rejection mixers in the up/down converters provide additional rejection.

By incorporating IPTV services to the WiMAX devices and envisioning that the mobile users watch a movie or a game that can last hours, the power consumption issue in WiMAX devices is exacerbated. The proposed radio structure is designed in such a way to minimize the power consumption. For example, most of the radio components have power down mode, which can be activated dynamically by PHY processor. Moreover, receiver sensitivity is an extremely important performance parameter to reduce power consumption in IPTV applications. Since the transmitter power level and receiver sensitivity are inversely proportional, having good receiver sensitivity lower the required transmit power level, which leads to longer battery life.

Noise Figure (NF) is a good indicator for the receiver sensitivity. The low-noise amplifier (LNA) employed has typical NF of 2dB. The LNA device includes switchable attenuation (10dB), a balanced mixer, a variable gain IF amplifier and a differential LO Buffer for improved performance. The LNA device can provide 28dB gain with 20dB gain control. A 10dB switchable attenuator is introduced in the RF path as well as 10dB of analog IF gain control to maximize input dynamic range. In order to provide better noise immunity at the mixer an on-chip balun converts the signal from single ended to differential form.

By having programmable DUC/DDC and CFR processor, the quality of IPTV services can be improved. These devices are designed for high-speed and high-bandwidth digital signal processing applications along with the capability of flexible digital filtering. Such features usually are demanded by IPTV applications.

The proposed radio structure has a capability to support three sectored antennas along with three radio cards. The sectored antenna systems are high-gain antennas that have property of transmitting further and listen better of the signals. By employing the sectored-antenna systems, high quality IPTV services can be delivered to both fixed and mobile users. The IPTV services can take benefits of the advantages of these three radio structures. Another uniqueness of the proposed radio structure is support of TDD, FDD, and H-FDD radio structures with very minimal change in hardware.

V. Conclusion

With WiMAX offering high data rates to both mobile and fixed users, and the desire of users to watch real-time TV or VoD services make the implementation of IPTV over WiMAX an exciting killer application. Realization of IPTV will enable users to have VoD services as well as to subscribe whichever channel of their choice giving them the a great deal of flexibility. LOGUS Wireless has been developing WiMAX based BS's that can provide IPTV service both to fixed or mobile users, and hence it can enable wireless connectivity anytime and anywhere.

References

[1] WiMAX Forum, Available online: http://www.wimaxforum.org
[2] IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems.
[3] Xilinx Virtex 4 FPGAs, Available online : http://www.xilinx.com/products/silicon_solutions/fpgas/virtex/virtex4/index.htm.
[4] Zhou, J. and Chen, J. and Zhao, J. and Wang, J. and Kang, W., "Design of a High Performance RF Transceiver for WiMax Basestation", Microwave Conference Proceedings, 2005. APMC 2005. Asia-Pacific Conference Proceedings, vol. 5, 2005.
[5] Balvinder Bisla, Roger Eline,and Luiz M. Franca-Neto, "RF System and Circuit Challenges for WiMAX", Intel Technology Journal, Vol. 8, Issue 3, pp. 189-200, 2004.