UTILIZING WiMAX MESH MODE FOR EFFICIENT IPTV TRANSMISSION

by

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ABSTRACT

UTILIZING WiMAX MESH MODE FOR EFFICIENT IPTV TRANSMISSION

In this thesis, an alternative model is proposed for the distribution of IPTV in wireless environment. Considering the data rate requirements of the IPTV service and challenges in distribution of the service due to wireless environment, our proposed model is built on the Mesh operating mode of the standard IEEE 802.16 (a.k.a, WiMAX). Besides the high data rates provided by the WiMAX technology, the capability of relaying transmissions and the adaptability to changing environment brings the WiMAX Mesh mode as a viable alternative to the infrastructure based models.

In our proposed model, the standard WiMAX Mesh mode is modified in order to meet the strict delay requirements of the IPTV service. Accordingly, transmissions are carried over only high data rate links and connections with up to two hops to the BS are allowed. Additionally, benefiting from space diversity information, parallel transmissions are utilized to save transmission slots, and allow serving more users. The simulation results show that, for the given delay constraints, the proposed model improves capacity compared to the standard WiMAX Mesh mode at the cost of omitting a few nodes (less than 1%) for which the experienced channel quality is too low for IPTV service anyways.

ÖZET

WiMAX AĞ ÇALIŞMA MODUNUN VERİMLİ IPTV YAYINI İÇİN KULLANIMI

Bu tezde, kablosuz ortamda IPTV yayını için alternatif bir çözüm önerilmektedir. IPTV servisi için gereken veri aktarım hızları ve kablosuz yayınlarda karsılaşılan güçlükler düşünülerek, modelimiz WiMAX olarak da bilinen IEEE 802.16 standartının ağ çalışma modu üzerine kurulmuştur. WiMAX teknolojisi ile sağlanılan yüksek veri aktarım hızlarının yanında, aktarımları iletme becerisi ve değişen çevreye adaptasyon kabiliyeti WiMAX ağ çalışma modunu altyapı tabanlı modellere karşı uygulanabilir bir alternatif haline getirmektedir.

Önerilen modelde, standart WiMAX ağ çalışma modu, sıkı gecikme gereksinimlerini karşılayabilmek için değiştirilmiştir. Buna göre, aktarımlar sadece yüksek veri aktarım hızına sahip bağlantılar üzerinden yapılmaktadır ve baz istasyonuna en fazla iki adımda olan bağlantılara izin verilmektedir. Ek olarak, alansal ayrıklık bilgisinden yararlanılarak, efektif olarak daha çok kullanıcıya hizmet vermede kullanabilecek aktarım dilimleri kazandırmak için, eş zamanlı aktarımlar düşünülmüştür. Sonuçlarımız, kanal kalitesi kötü olduğu için sadece daha gürbüz modülasyon düzenleri kullanılarak ulaşılabilen az sayıdaki (%1'den daha az) düğümün ihmal edilmesi karşılığında, standart WiMAX ağ çalışma moduna göre daha fazla kullanıcıya hizmet verilebildiğini göstermektedir.

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R_b	Raw Bit-rate
N_{used}	Number of Active Subcarriers
b_m	Number of Bits per Modulation Symbol
c_r	Coding Rate
T_s	Total Bit Duration
R_{stc}	Space-time Coding Rate

LIST OF ABBREVIATIONS

APSK	Amplitude Phase Shift Keying
BE	Best Effort
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BS	Base Station
CBT	Core-Based Tree
CID	Connection ID
DSL	Digital Subscriber Line
DCD	Downlink Channel Description
DL-MAP	Downlink MAP
ertPS	extended real-time Polling Service
FDD	Frequency Division Duplexing
HD	High Definition
HDTV	High Definition Television
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPTV	Internet Protocol Television
LOS	Line of Sight
MAC Layer	Medium Access Control Layer
MDC	Multiple Description Coding
MIMO	Multiple Input Multiple Output
MSS	Mesh Subscriber Station
NLOS	Non-Line of Sight
nrtPS	non real-time Polling Service
OFDMA	Orthogonal Frequency Division Multiple Access
PHY Layer	Physical Layer
PMP	Point to Multipoint
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service

QPSK	Quadrature Phase Shift Keying
rtPS	real-time Polling Service
RS	Relay Station
SCM	Superposition Coded Multicasting
SD	Standard Definition
SDTV	Standard Definition Television
SISO	Single Input Single Output
SINR	Signal to Interference Noise Ratio
SNR	Signal to Noise Ratio
TDD	Time Division Duplexing
UCD	Uplink Channel Description
UL-MAP	Uplink MAP
UGS	Unsolicited Grant Service
SS	Subscriber Station
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WISDoM	Wireless IPTV Service Distribution over Mesh Mode
WISDoM-Hybrid	Wireless IPTV Service Distribution over Mesh Mode Hybrid
WISDoM-SD	Wireless IPTV Service Distribution over Mesh Mode benefiting from Space Diversity

1. INTRODUCTION

The rapid advances in telecommunication technologies have increased the interest in advanced Internet applications. Providing digital television over the Internet Protocol (IP) at low costs, the Internet Protocol Television (IPTV) [1–3] has become one of the most popular multimedia video streaming applications in recent years. This bandwidth hungry application is also expected to play a key role for future business growth of the next-generation broadband Internet technologies. Due to competitive pressure in the telecom market, many operators have already expanded their services to triple-play (data, voice, and video services) or even quadruple-play services (triple-play services plus mobility) on a single infrastructure to stay in the market and to prosper as well [2, 4].

The wireless standard IEEE 802.16, so called WiMAX (World Interoperability for Microwave Access) [5], is one of the most promising next-generation wireless technologies, which has the potential to provide IPTV service effectively with high data rates and long transmission ranges supported by the recent IEEE 802.16m WiMAX systems [6]. Although some advanced wired methods such as Digital Subscriber Line (DSL), cable, or fiber may meet the bandwidth requirements for the IPTV service, a high quality wired infrastructure is required for these technologies to operate. Considering the geographical structure of the environment, it may be difficult to deploy such an infrastructure. Furthermore, deployment of a wired network is more expensive compared to wireless technologies. Therefore, there is a great interest in alternative broadband wireless techniques. At this point, the ease of deployment and adaptability to changes in topology bring WiMAX as a reasonable alternative to the wired techniques [7–9].

There are basically two operating modes defined in WiMAX (starting from IEEE 802.16d standard), namely the Point-to-Multipoint (PMP) and the Mesh operating modes. Among these two, the PMP mode has a similar infrastructure to IEEE 802.11 networks [10]. There exist two types of devices in the PMP mode: the Base Station

(BS) and the Subscriber Station (SS). The BS manages the network traffic, and the mobile (e.g., pedestrians or vehicles) and fixed (e.g., buildings) SSs have to connect directly to the BS in order to receive service. Similar to the PMP mode, there are two types of devices in the Mesh mode, namely the Mesh BS[1] and the Mesh Subscriber Station (MSS). In the Mesh mode, the BS controls the network traffic similar to the PMP mode. However, different from SSs in the PMP mode, the MSSs in the Mesh mode have the ability to connect to other subscribers and have their transmissions relayed over those subscribers in an ad-hoc manner.

Considering the high data rate requirement for the IPTV services and the limited spectral resources, the establishment of high data-rate connections is essential to meet the delay requirements for the IPTV service and distribute the IPTV service effectively. However, in metropolitan areas, it is generally hard to establish a high data-rate connection to the BS directly. A station may even fail to establish any connection to the BS at all due to geographical structure of the environment. At this point, utilization of the Mesh mode operation plays the key role of enabling the subscriber stations, which are not able to connect to the BS using a high capacity modulation coding scheme, to receive IPTV service effectively. Via the Mesh mode operation, these stations can connect to an available MSS which has a high data rate connection to the BS and this MSS can relay their transmissions.

The delivery mechanism also plays a vital role for the distribution of IPTV service over WiMAX. Since there is a requirement for transmission of the video bitstreams of a TV channel to multiple users, multicasting can be adopted for efficient delivery of this same data to multiple receivers simultaneously. Clustering the users who are tuned to the same TV channel in a single multicast group, the whole group can be served with a single transmission consuming less bandwidth [11].

In wireless networks, all users in a multicast group may not necessarily experience the same channel conditions. While a user's channel quality may enable high bit-

[1] The BS in the WiMAX Mesh mode is called Mesh BS. For simplicity, the Mesh BS in the WiMAX Mesh mode is referred to as BS in the text

rate modulations at high signal-to-noise ratio (SNR), a bad channel quality and low SNR may enforce the use of a more robust but low capacity modulation scheme. As mentioned in [4, 11], this multiuser channel quality diversity is considered as one of the biggest challenges in multicasting in wireless environments.

The multiuser channel diversity problem can be solved trivially by using separate data streams to broadcast a requested IPTV channel for each type of modulation used by subscribers requesting this channel. As a result, the same data for an IPTV channel is broadcast multiple times using the requested modulation-coding schemes for the same multicast group. Considering the limited spectral resources, these retransmissions of the same data degrades the performance of the network significantly.

In [4] and [12], the authors combine layered video approaches like Multiple Description Coding (MDC) [13] in the application layer and Super Position Coded Multicasting (SCM) [14] in the physical (PHY) layer to solve multiuser channel diversity problem effectively. These techniques reduce multicasting into a single transmission and thereby achieve significant bandwidth savings. However, there is a quality assurance problem with these models. It should be noted that each user receives service according to the maximum available instantaneous signal quality. From network utilization perspective, this approach is equivalent to forcing all of the the users to communicate with the more robust, low capacity modulation schemes. This approach also constitutes a problem in practice since users who can be served at most in SDTV quality due to bad channel conditions will be unwilling to pay the same price with those receiving in HDTV quality. Moreover, these models do not address helping the users who are unable to establish any connection to the BS at all.

In the literature, there are also other approaches like [15] and [16], which aim at avoiding retransmissions due to multiuser channel diversity via cooperative transmissions and while enabling access to the uncovered users. Although the models address effective distribution via cooperation within the multicast group, an important problem with these models is the instability in path delays. These models do not consider the condition in which the whole multicast group is positioned such that the transmission from BS to the relay nodes can only be accomplished over low data-rate links. Similarly, the users within the multicast group may be positioned such that the relaying (i.e., cooperation) can only be carried over low data-rate links. Considering these two possibilities, which significantly degrade the network performance, tolerable delay limits for the IPTV application can easily be exceeded. Therefore, stable distribution models with less deviating path delays should be utilized.

Taking these approaches into consideration, we extend our previous work in [17] and propose an alternative IPTV distribution model, which improves the multicast and the Mesh mode operation features of WiMAX. The spectral efficiency of the system is improved by utilizing a two-hop multicasting method using a single enhanced (i.e., high capacity) modulation-coding scheme at each hop instead of utilizing a low capacity modulation in single hop. The proposed model utilizes the Mesh mode operation to support the users who are either unable to connect to the base station at all or can connect only using a low capacity modulation scheme. Additionally, in the proposed model, the efficiency of the Mesh mode operation is further improved by parallel transmissions, benefiting from spatial diversity.

1.1. Contribution of the Thesis

In this thesis, we propose a solution for the distribution of IPTV service, called WISDoM-SD (Wireless IPTV Service Distribution over Mesh mode benefiting from Space Diversity), based on WiMAX standard IEEE 802.16 Mesh mode operation [18]. The spectral efficiency of the standard WiMAX Mesh mode operation has been improved for efficient IPTV broadcasting via:

- Utilizing a two-hop multicasting method using an enhanced (i.e., high capacity) modulation-coding scheme at each hop instead of utilizing a low capacity modulation in single hop.
- Avoiding retransmissions due to the multiuser channel diversity problem by transmitting with a single chosen modulation scheme at each hop.
- Utilizing parallel transmissions benefiting from spatial diversity.

1.2. Organization of the Thesis

The organization of the thesis is as follows. In Chapter 2, the background information for the basic concepts of our proposed model are briefly summarized. In Chapter 3, a survey of previous studies on our subject is presented, and the proposed models are examined and evaluated. The WISDoM-SD model, is explained in detail in Chapter 4. In Chapter 5, the simulation results are presented and evaluated. Finally, the thesis is concluded and the future work is mentioned in Chapter 6.

2. BACKGROUND INFORMATION

In this section, we provide the basic background information on WiMAX and IPTV required for the discussion of our proposed model.

2.1. WiMAX

In our daily life, most of the time we are bound to limitations due to the wired infrastructures, especially if we want high data rates and reliable connections. Current wireless solutions partially solve the problems with wired infrastructures, but they mostly suffer from short range and limited bandwidth. However, there are a number of WMAN solutions under development, intended to solve the range and bandwidth issues of the wireless solutions.

One of the most promising WMAN technologies is IEEE 802.16 (a.k.a., WiMAX (Worldwide Interoperability for Microwave Access)). It is developed with the basic aim of creating an alternative metropolitan area broadband wireless solution to the conventional fixed (i.e., wired infrastructure) broadband technologies such as cable, DSL, or fiber. The outstanding capabilities proposed in terms of bandwidth and range bring WiMAX a feasible alternative to the wired infrastructures.

Similar to Wi-Fi alliance, there is the WiMAX forum, formed in June 2001, which works to promote conformance and ensure interoperability issues with the IEEE 802.16 standard. It aims at solving the potential problems that may emerge from compliance issues for devices from different vendors.

The standardization of WiMAX began in December, 2001. Initially, only the PMP operating mode was defined for fixed Line of Sight (LOS) communication at a frequency range of 10 to 66 GHz. For this very first standard, the typical cell radius is 1 to 3 miles and the maximum aggregate data rate is 135 Mbps.

The difficulty of LOS communication especially in the urban areas eventually led to the development of a new PHY layer with a Non-Line of Sight (NLOS) capability. As a result, an amendment, IEEE 802.16a, was introduced in January 2003 in order to support NLOS communication. Multipath propagation is essential for NLOS communication. However, it is hard to achieve high signal strength in high frequency bands considering multipath propagation. Thus, a lower frequency band, 2-11 GHz, is considered for NLOS operation. Additionally, besides the PMP mode, a second operation mode, the Mesh mode, is defined with this amendment.

The standard IEEE 802.16d was introduced in 2004 as the outcome of a revision project. Various amendments to the earlier IEEE 802.16 documents are clarified and conformance issues related with these documents are solved in this newer standard.

One of the most outstanding improvements for WiMAX, mobility support, was introduced with the IEEE 802.16e amendment in 2005. Therefore, this amendment is also known as "Mobile WiMAX". In order to support mobility, the frequency band between 2 and 6 GHz is considered for operation. Additionally, the quality of service in earlier 802.16d standard is revised with this amendment.

In 2009, two major amendments, the multi-hop relaying support for the PMP mode operation in IEEE 802.16j and improved coexistence mechanisms for license-exempt operation with IEEE 802.16h, are introduced.

The latest version of the WiMAX standard, IEEE 802.16m (a.k.a., Mobile WiMAX Release 2 or WirelessMAN-Advanced), has been approved recently on May 6, 2011. It introduces a new MIMO PHY layer and theoretically supports data rates up to 100 Mbps for mobile applications and 1 Gbps for fixed applications. In our model, we also consider the data rates for this standard.

2.1.1. Operating Modes in WiMAX

As mentioned before, there are two operating modes defined in the WiMAX standard, namely the Point-to-Multipoint and the Mesh modes.

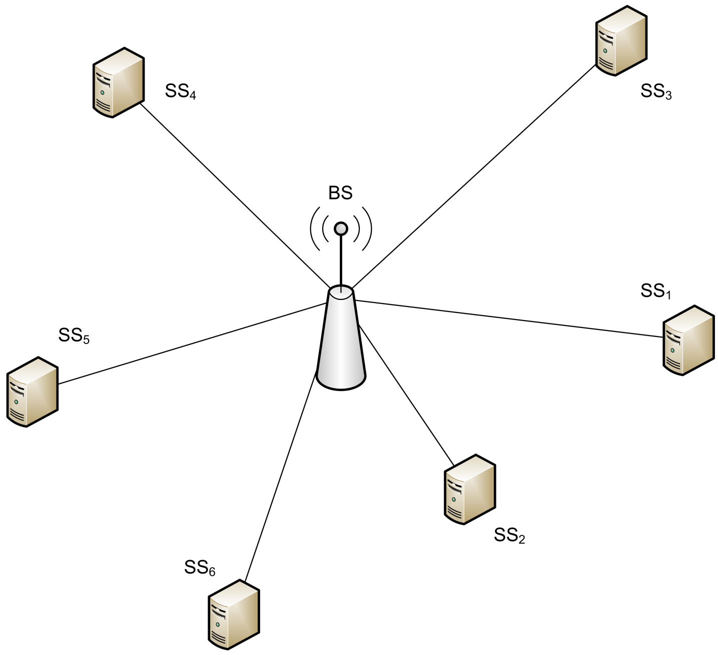

Figure 2.1. WiMAX PMP Mode Configuration.

In the PMP mode, the network consists of two types of devices, the BS and the SS. The SSs can be either mobile (e.g., pedestrians or vehicles) or fixed (e.g., buildings). All SSs connect to the network over the BS. Even if the subscribers are in close proximity, direct communication between the SSs is not allowed and all the data flow is carried through the BS. The BS manages all the network traffic and makes the scheduling of the requests.

There are five types of QoS service classes defined in the PMP mode operation, namely Unsolicited Grant Service (UGS), extended real-time Polling Service (ertPS), real-time Polling Service (rtPS), non real-time Polling Service (nrtPS), and Best Effort (BE) in the priority order. UGS is generally used for constant bit rate (CBR) traffic or T1/E1 services, and the agreed bandwidth is always allocated the SS whether it is used or not. ertPS is another high priority class, used for VoIP and similar applications for which bandwidth allocation can be adjusted according to utilization. Thirdly, rtPS service class is used for real-time applications with variable bit rate (VBR) traffic such as sound, video, etc. On the other hand, non real-time applications which have no strict latency constraints but have a minimum reserved bandwidth use the nrtPS service class. Finally, the lowest priority BE class is used for non-time-critical applications and there is no bandwidth reservation for this service class.

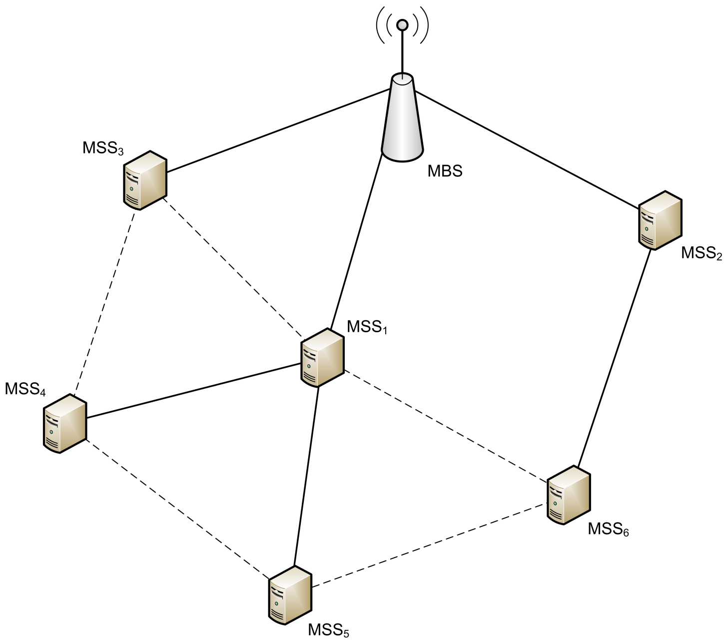

Figure 2.2. WiMAX Mesh Mode Configuration.

Similar to the PMP mode, the network in the Mesh mode consist of two types of devices. There is a Mesh BS that controls the network traffic. However, instead of simple subscriber stations as in the PMP mode, there are MSSs which have the ability to communicate directly with neighbor (i.e., one hop away) subscribers. Accordingly, the Mesh mode operation provides connectivity for subscribers in order to relay their transmission via the other subscribers especially when the received signal strength of the subscriber does not allow direct communication with the BS because of the physical/environmental circumstances. An MSS, that fails to establish a connection to the BS due to bad channel quality can connect to an available neighbor MSS, which can relay its transmission in the Mesh mode operation.

In the relay scenario, the relaying MSS is called the parent node of the MSS for which relaying is done. The MSS which is served by the parent MSS is called the child node. The links established between the parent nodes and the child nodes construct the centralized routing tree, and the links of this tree are called the centralized links (shown with solid lines in Figure 2.2). The rest of the links established between the neighboring nodes are called the distributed links (shown with dashed lines in Figure 2.2).

In accordance with the centralized and distributed link types, there are two types of scheduling in the Mesh mode: centralized scheduling and distributed scheduling. Similar to scheduling in the PMP mode, all the traffic is managed by the BS in the centralized scheduling, and the transmissions are conducted over the centralized links of the network. On the other hand, the distributed scheduling is used for transmissions over the distributed links between the neighbors. Typically, the distributed scheduling is used for intranet traffic whereas the centralized scheduling is used for the Internet traffic.

2.1.2. Frame Structures in WiMAX

In IEEE 802.16 networks, the transmission is divided into frames which have fixed length. The frame length is set during the initialization of the network. In case of a change in the frame length, all the SSs are required to resynchronize with the BS.

There are two different frame structures defined in the PMP mode. These are Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) frame structures as shown in Figures 2.3 and 2.4, respectively. In both of these frame structures, the frame consist of two subframes: downlink and uplink subframes. The uplink subframe is used for transmissions from the SSs to the BS, and the downlink subframe is used for transmissions from the BS to the SSs. A frame is divided into a number of Physical Slots (PSs) and the adjacent PSs that are allocated to the same connection are called bursts.

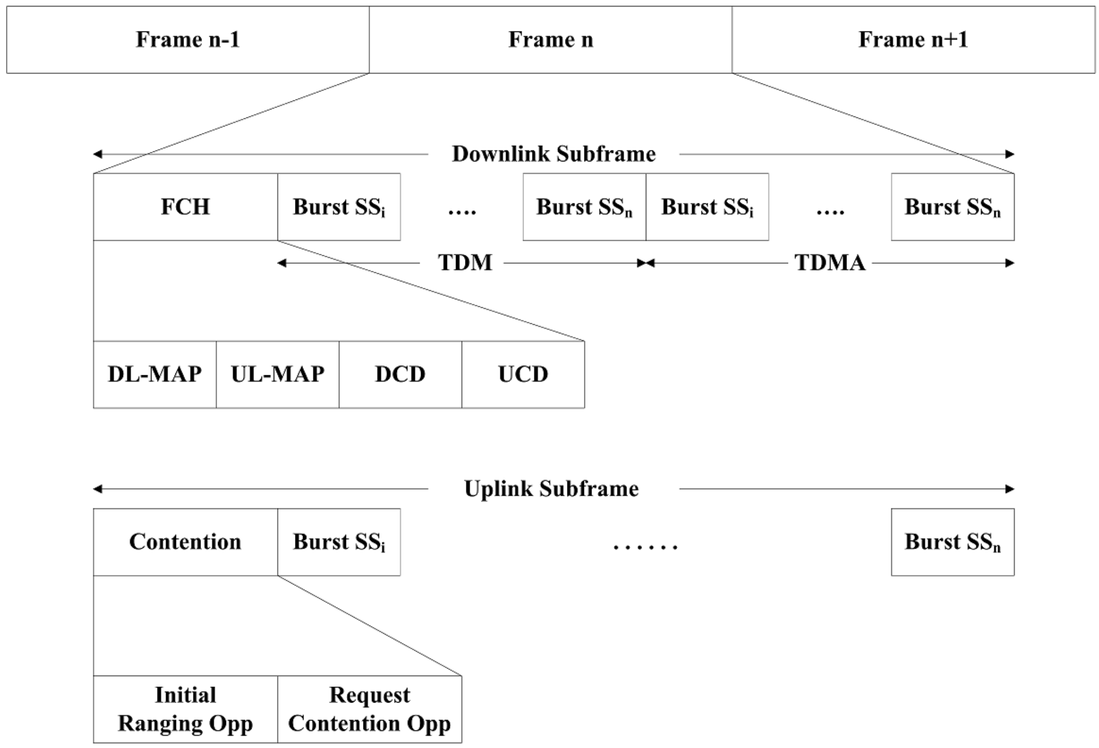

Figure 2.3. WiMAX PMP Mode FDD Frame Structure.

In FDD frame structure, the uplink and downlink subframes are transmitted simultaneously using different frequencies. On the other hand, in the TDD frame structure, the uplink and downlink subframes are transmitted in sequential time periods using the same frequency.

At the start of the downlink subframe, there exists a Frame Control Header (FCH) which is composed of four types of messages: DL-MAP (Downlink MAP), UL-MAP (Uplink MAP), DCD (Downlink Channel Description), and UCD (Uplink Channel Description). The DL-MAP and UL-MAP specify the downlink and uplink PS allocations to the bursts. The modulation and coding rate of connections are not fixed. Therefore, each connection may use different modulation and coding schemes (i.e, burst profiles). In order to describe the use of the burst profiles to the SSs, periodic DCD and UCD messages are included in the FCH, and this period is decided by the BS. Following the FCH, data transmission is conducted and SSs sequentially transmit

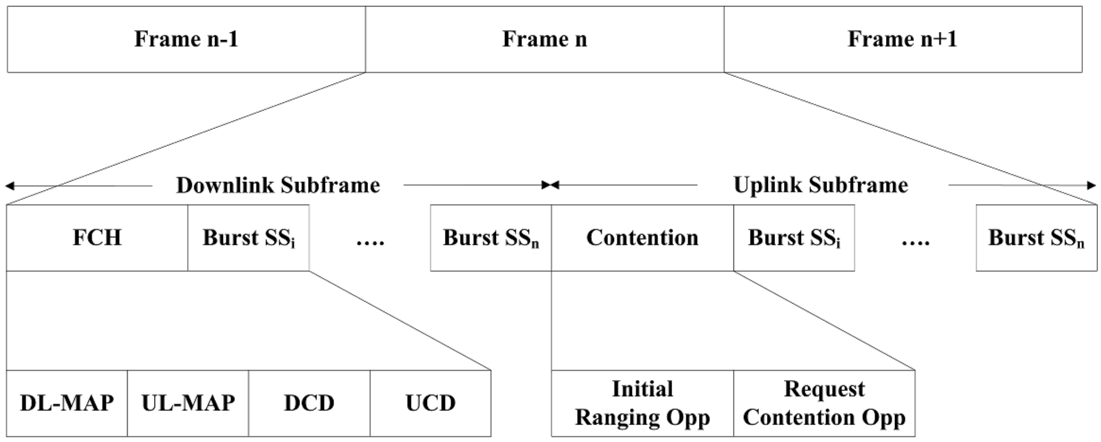

Figure 2.4. WiMAX PMP Mode TDD Frame Structure.

their downlink data during their allocated bursts. Additionally, there exists a TDMA part in FDD structure for half-duplex SSs.

Instead of the FCH at the beginning of the downlink subframe, the uplink subframe starts with a contention-based part. In the beginning of this contention-based part, initial ranging and initialization processes of the new SSs take place. Following these, the SSs request and contend for PS allocation for their nrtPS and BE connections. After the contention-based part, SSs sequentially transmit their uplink data during their allocated bursts similar to the data transmission in the downlink subframe.

Different from the the PMP mode, only TDD frame structure is defined in the Mesh mode. As shown in Figure 2.5, the Mesh mode TDD frame structure has fundamental differences from the frame structures in the PMP mode. Every frame consists of a control subframe and a data subframe following this control subframe. Additionally, each of these subframes is divided into two parts as one part for centralized scheduling and another part for distributed scheduling. The control subframe can either be used for periodic network controls or scheduling of the data transmissions. The control subframe consists of Transmission Opportunities (TOs) each of which is composed of seven OFDM symbols. The number of TOs is set during the initialization of the network. On the other hand, the data subframe consists of minislots whose size is determined according to the PHY layer parameters, and the number of minislots in the data subframe is always 256. While different modulation and coding schemes can be used during data transfers, QPSK modulation scheme with 1/2 coding rate is used for all the transmissions in the control subframe.

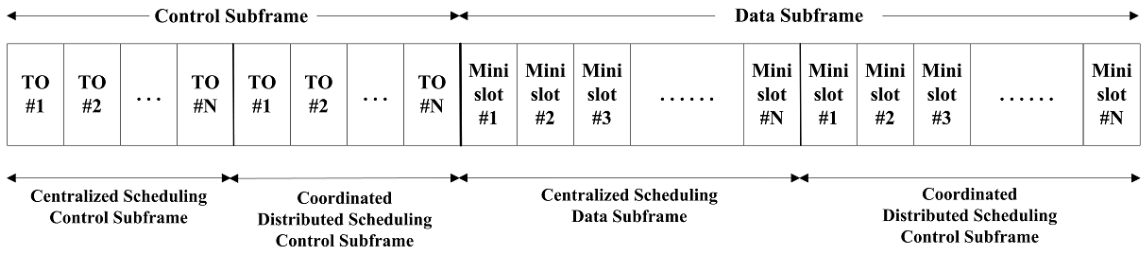

Figure 2.5. WiMAX Mesh Mode FDD Frame Structure.

2.1.3. Capacity of WiMAX

In a wireless environment, all the users in the network do not necessarily experience the same channel quality due to environmental and geographical factors. At this point, connections may utilize different burst profiles (i.e., modulation and coding schemes) in order to deal with variations in air link quality (depending on the PHY layer). The burst profiles are usually based on the distance between the BS and SS as shown in Figure 2.6. Although user equipments demand for highest data-rates, modulation techniques cannot preserve healthy communication with users beyond some specific distance to the base station.

Besides the distance to the BS, there are also other loss factors that affect signal quality such as multi-path fading, doppler spread, and co-channel and adjacent channel interference, which prevent usage of high capacity burst profiles. The burst profile of a connection is not fixed in WiMAX. The users may change their burst profiles depending on the status of the medium. As well as a users channel quality may enable the user to use a high bit-rate burst profile at high SNR, bad channel quality and low SNR may enforce the use of a more robust but low capacity burst profile.

The raw bit-rate, R_b, for each modulation can be calculated according to the

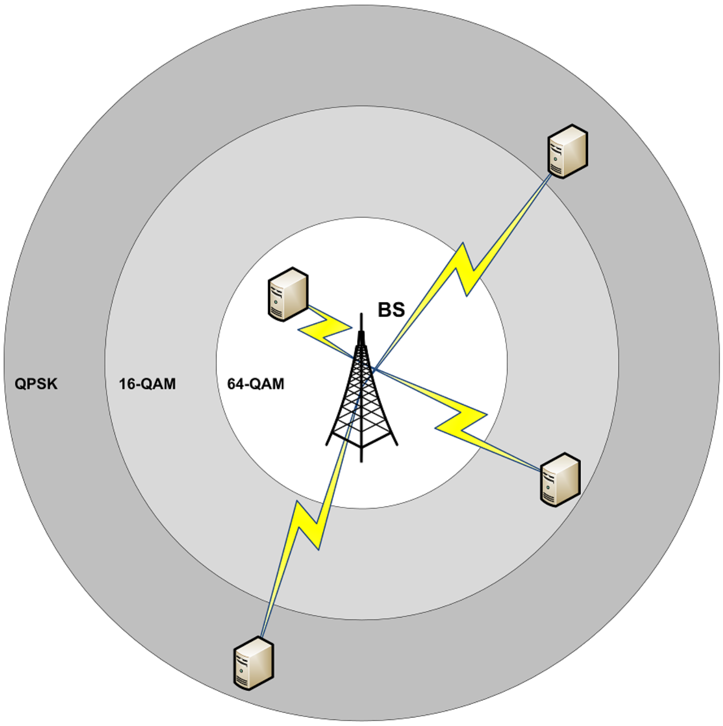

Figure 2.6. WiMAX Adaptive Modulation Coding.

following formula from the IEEE 802.16 standard [19]:

$$R_b = \frac{N_{used}.b_m.c_r}{T_s} \tag{2.1}$$

where N_{used} is the number of active subcarriers, b_m is the number of bits per modulation symbol, c_r is the coding rate, and T_s is the total bit duration.

Imposing the MIMO's multiple streaming property into the previous equation, the raw bit rate R_b becomes:

$$R_b = \frac{N_{used}.b_m.c_r}{T_s}.R_{stc} \tag{2.2}$$

where R_{stc} is the space-time coding rate.

In agreement with the drafts for the standard IEEE 802.16m [20], we consider using 2048 OFMDA (1728 active subcarriers) and a 20 MHz bandwidth together with a 4x4 MIMO antenna system which quadruple throughput (i.e., R_{stc}=4) [21]. The highest bit-rates supported for various modulation and coding rate combinations are given in Table 2.1.

Table 2.1. Raw Bit-rates for WiMAX (20 MHz, 2048 OFDMA, 4x4 MIMO).

Modulation	$CodingRate$	$Bit-rate$ (Mbps)
BPSK	1/2	~ 33
QPSK	1/2	~ 66
QPSK	3/4	~ 100
16-QAM	1/2	~ 133
16-QAM	3/4	~ 199
64-QAM	2/3	~ 266
64-QAM	3/4	~ 299
64-QAM	5/6	~ 332
256-QAM	3/4	~ 398
256-QAM	5/6	~ 443

It should be noted that these calculated data rates are raw data rates and the practical data rates will be lower.

2.2. IPTV

The IPTV has become one of the most popular multimedia Internet applications in recent years. Compared to traditional cable TV services, it is a combination of broadcasting and telecommunication offering a wide range of services including Video on Demand (VoD), Voice over IP (VoIP), and Web/email access over the Internet Protocol (IP). Providing these voice, video, and data services (a.k.a, triple play services) at low costs, it has drawn the attention of the users and become an important revenue opportunity for the service providers as well.

Nevertheless, the high data rate requirement for these services enforces the operators to make further investments in broadband technologies as mentioned in [2]. The typical video compression rates for a Standard Definition TV (SDTV) channel and a High Definition TV (HDTV) channel are listed in Table 2.2.

Table 2.2. Video Compression Rates [3].

	SDTV	**HDTV**
MPEG-2	2 - 4 Mbps	16 - 19 Mbps
H.264	1.5 - 2 Mbps	6 - 8 Mbps
WM9 (VC-1)	1.5 - 2 Mbps	6 - 8 Mbps

As can be observed from the table, the advanced video coding schemes like H.264 (a.k.a, MPEG-4 part 10 or MPEG-4 Advanced Video Compression) or the WM9 noticeably perform better by providing good video quality at significantly low data rates compared to the MPEG-2 standard.

According to the raw bit-rates given in Table 2.1, the total bandwidth of a robust modulation scheme such as QPSK scheme with coding rate 1/2 is $\sim 66\ Mbps$. Considering the 6 $Mbps$ bandwidth requirement for a single HDTV channel, the number of HDTV channels that can be supported by this QPSK scheme is only 11 (without considering the overhead of the control messaging). Although the condition is a little improved with modulation schemes such as $16 - QAM$ scheme with coding rate 3/4, which has a total bandwidth of $\sim 199\ Mbps$, at most $\lfloor 199\ Mbps/6\ Mbps \rfloor = 33$ HDTV channels could be served with this $16-QAM$ scheme. As a result, both QPSK and $16-QAM$ schemes seem practically insufficient for single-hop IPTV transmissions, let aside a two-hop relay mode. Therefore, instead of single transmission with low capacity modulations such as QPSK and $16-QAM$, relaying with higher capacity modulation techniques such as $64-QAM$ can be used to serve more IPTV channels.

3. LITERATURE SURVEY

In recent years, with the development of broadband communication technologies, the interest in advanced Internet applications like IPTV has rapidly increased and many studies have been put forward on IPTV service models. [4,11,22] present comprehensive studies about the basic concepts, applications, and services for IPTV and identify the challenges in distribution and management of the IPTV systems.

In [22], a framework for delivering IPTV services over WiMAX wireless networks is proposed. The paper describes the key concepts for the operation of IPTV services and applications for IPTV services in detail, and outlines the basic requirements and challenges in the network infrastructures associated with IPTV service delivery. Addressing these requirements and challenges, the fundamental features of WiMAX are stated for medium access control (MAC) and PHY layers of the IPTV service framework. Similarly, another framework design for IPTV service distribution over WiMAX systems is proposed in [11]. While discussing the challenges associated with delivery of IPTV content, the fundamental features of WiMAX systems like the inherent multicast capability and the mobility support, which make WiMAX a viable solution to support IPTV services framework, are presented. Besides the basic MAC and PHY layer considerations to deliver and manage the IPTV services effectively, a high-performance radio transceiver model is proposed at the PHY layer. However, no simulations are presented for these two proposed framework designs in [11, 22].

As mentioned in studies [4,11,22], multicasting plays a major role for applications like IPTV in which delivery of the same data to multiple users is required. Simultaneously delivering video bitstreams of a TV channel to multiple users and thereby using relatively small bandwidth compared to unicast schemes, it is generally adopted as an efficient way of delivery of the service. However, multicasting in wireless environment is one of the most challenging issues in IPTV distribution, and therefore there has been a great interest on this subject in the literature.

Basically, the proposed solutions for multicasting in the literature can be categorized according to the mode of operation considered for the design. That is, either the solution is designed for single-hop (i.e., PMP mode) operation as in [4,12,15,16,23–29] or multi-hop (i.e., PMP mode with relay stations or Mesh mode or ad-hoc) operation as in [30–37].

In [23], a MAC layer multicasting approach for the WiMAX PMP mode operation is proposed. The model aims avoiding the duplicated copies of multicast IP datagrams for the SSs in a multicast group, which may cause significant bandwidth consumption especially for crowded networks. In the proposed approach, the SSs are enabled to identify the multicast group in the MAC layer via addition of an extra multicast IP address field to the WiMAX MCA-REQ message, which is used for adding/removing a SS to/from a multicast group. Thereby, upon receiving a MCA-REQ message, the SSs can easily identify the multicast group and decide to join or leave the group at this time. Additionally, the BS assigns the same CID to every SS in a multicast polling group and stores the multicast IP address of the group, coupling it with this same CID. As a result, the multicast packet to a multicast group is delivered with a single transmission, and multiple unicasting to the SSs in the multicast group is avoided. With the simulations, the authors show that the network traffic can be reduced significantly by avoiding duplicated datagrams, and thereby higher throughput and more importantly lower packet delays can be achieved. Since the scheme is directly designed for single multicast flow performance, it works fine in existence of a single multicast flow. However, the existence of unicast packets or multiple multicast flows may be problematic. Since the same CID is allocated to the users in a multicast group, it will cause a confusion between service flows and inevitably some modifications in the message flows and formats will be required for the usage of CID in this way.

A similar usage of CID is observed in [30] for the WiMAX Mesh mode operation. In the WiMAX Mesh mode operation, only unicast transmission is specified and multicast transmission is left as an open subject. In [30], Chen *et al.* propose a bandwidth efficient multicasting scheme for WiMAX Mesh networks. Utilizing the scheduling messages defined in the WiMAX standard, they propose a multicast tree construction mechanism based on the adjustment of the centralized routing tree. The scheme considers a CID usage, which is same as the scheme in [23]. The same CID is assigned for the SSs in a multicast group. Designed for only single multicast flow performance compared to traditional multiple unicasting method, the proposed multicasting solution achieves significant bandwidth savings. However, the same concerns as in [23] apply for this scheme. The appearance of unicast packets or multiple multicast flows needs further studying and essential improvements are required in the message flows and formats for such use of CID.

In [24], Chen *et al.* propose an approach to increase efficiency while providing reliability in multicast and handoff processes for WiMAX multicast applications. The model is based on Core-Based Tree (CBT) [38] data forwarding scheme in which only a single shared multicast tree is built for each multicast group. In order to realize this forwarding scheme, all the routers in the network are complemented with the multicast-capable functionality, and these multicast-capable routers constitutes the core of the scheme. The model proposes the Reliable Multicast Protocol 2, which guarantees that the multicast packets are received in sequence and without any packet loss. In order to reduce the load on the multicast source due to retransmission requests, the entire retransmission requests are carried over a fixed node, the local agent, selected by the source. In case of packet loss or reception of a corrupted packet, the host reports this incidence to the local agent by sending a Negative Acknowledgement (NACK), and the local agent processes these NACKs and requests for retransmission of these packets from the source. Afterwards, the local agent delivers these packets to the mobile clients either via multicasting or unicasting dynamically according to the traffic load. When the number of NACKs is low, the requested packets are unicast to the clients. Alternatively, in a heavy traffic load case, the local agent utilizes multicasting to send these requested packets to the mobile clients. Although this approach reduces the traffic for the recovery of the packet losses, it should be noted that for a delay-intolerant application like IPTV, the retransmission of the packets may cause further timing problems considering the scarce resources.

The local agent in [24] is additionally utilized for handling the handoff process of the mobile clients. It is responsible for all foreign mobile clients and handles multicast group subscriptions and multicast transmissions of these nodes. Upon the movement of a client to another cell, in which the client's serving BS is changed but the current and the old serving SSs are members of overlapping multicast virtual groups, the main multicast delivery tree is preserved since the new serving SS and the old serving SS have already joined to the multicast tree before handoff. In this case, since both of the BSs have already been buffering the multicast packets of this mobile client, no forwarding of the packets from the old BS to the new BS is required, and the handoff process is shortened. The results show that for small number of users, unicast retransmissions do not cause a heavy load on traffic and even result in a better performance than the proposed multicasting approach. However, as the number of users and the number of duplicated retransmissions increase, the bandwidth savings due to the proposed multicasting scheme becomes significant, and it noticeably outperforms the unicast scheme in high network load. A similar reasoning can be applied for the handoff delays so that when the number of users are increased, the packets to be forwarded between the old and new BSs play a significant role on network traffic and make the proposed scheme perform faster handoff than the unicast scheme.

In [25], another mechanism is proposed for reliable multicasting in WiMAX networks efficiently. This scheme is also designed for the PMP mode operation. Considering the waste of uplink resources for the feedback of the SSs for the multicast service, the proposed scheme utilizes the orthogonal CDMA codes in IEEE 802.16 OFDMA system to enable the SSs to send their feedback simultaneously and thereby save significant amount of uplink slots. The proposed multicast service uses two types of codes, namely the Cumulative ACK (CA) code which is sent to indicate a successful reception and ARQ Feedback Request (AFR) code which is sent to indicate a packet loss. In order to avoid collisions during the feedback messaging, the BS assigns each SSs two orthogonal CDMA codes, CA and AFR codes, and these codes are reserved for this SS only. Compared to the scheme in which unicast feedback messages are used, this scheme results in significant uplink savings. A problem to mention about this scheme is the user capacity limitation. There are only 256 orthogonal CDMA codes to be used in IEEE 802.16 OFDMA system. Therefore, the maximum user capacity of the network is limited to 128 since each user is assigned two dedicated CDMA codes.

In [26], a cross-layer design in single-hop multicast networks is proposed. The model considers a multicast approach in which, the multicast receivers are queried for availability before each transmission. At this point, the paper points out the difficulty of having all the users of a multicast group ready for a given transmission rate at all times due to the varying channel conditions experienced. Therefore, an acceptable multicast Threshold-T Policy [39] is adopted for the MAC layer instead of waiting until all the receivers are ready in order to maximize the throughput of the system. According to this policy, the transmitter waits until T of M multicast receivers are ready to receive. Although utilizing a lower transmission rate is expected to shorten the waiting of the transmitter, lower rates obviously require longer packet transmission times. On the other hand, utilizing higher transmission rates may lower the packet transmission times but result in longer waiting times. In this respect, the paper studies a rate optimization method via adjustment of the T value to maximize throughput while maintaining stability of the network. Additionally, the model adopts an erasure coding approach, the digital fountain [40], in the transport layer in order to improve the reliability of the system since some receivers may fail to obtain some packets due to the Threshold-T Policy if $T < M$. Basically, in the digital fountain approach, the original k data packets are encoded into n packets ($n > k$) for which the original data can be reconstructed successfully using any k packets of these n packets. Consequently, the user may recover from packet losses up to h packets ($h = n - k$) due to temporary channel fluctuations. Formerly being considered for Single Input Single Output (SISO) links, the study is generalized for networks with Multi Input Multi Output (MIMO) and non-identical links. As far as the performance of the model is considered, although better reliability can be achieved via querying the users before transmission, it should be noted that the querying overhead may result in significant bandwidth consumption especially for large networks. For this reason, a small multicast group is considered in this paper. Additionally, in the QoS sense, the authors do not account for the users that may suffer due to the Threshold-T policy.

Considering the fact that the urban/suburban users use different modulation schemes since they experience various channel conditions, the same data are retransmitted with different modulations. In order to solve this multiuser channel diversity problem and avoid retransmissions, several layer encoding techniques have been proposed for efficient video/application multicasting. One of the most frequently adopted methods for video streaming for WiMAX is multi layer data coding, such as Multiple Description Coding (MDC) [13]. In MDC, a set of video bitstreams for a layer is encoded into several packets so that the more packets are received and decoded, the better video quality is achieved. While some models adopt these layer encoded video techniques and combine them with advanced PHY layer techniques to provide robustness besides solving multiuser channel diversity problem, others utilize these to find optimal resource allocation for maximum overall user satisfaction.

A PHY layer approach, 2-level Superposition Coded Multicasting (SCM) [14] scheme, is proposed to overcome the multi user channel diversity problem in wireless multicast in [4]. Superposition coding is a physical layer technique that allows simultaneous transmission of independent messages to multiple receivers by a single transmitter. In this model, each video frame of an IPTV channel is encoded into two layers, a base layer and an enhancement layer. Afterwards, the bitstreams of these two layers are embedded together in a single superposition coded multicast signal utilizing SCM. In order to provide a base video quality to every user, the base layer data is modulated by a low capacity but robust modulation scheme (such as BPSK) and the enhancement layer is modulated by a high data rate modulation scheme (such as 16-QAM). As a result, each user is able to obtain at least the base video quality, which is modulated by the BPSK scheme, when subject to bad channel state, or achieve the finest video quality in which all data are modulated by both BPSK and 16-QAM in good channel state. The proposed SCM solution is straightforward and ensures that the user receives an acceptable video quality at temporary fluctuations in the channel quality.

Considering this issue that preserving the video quality in case of short-term channel fluctuations is not addressed in [4], which solely employs superposition coding, a cross-layer design framework is proposed in [12] with the aim of recovering (or protecting) video quality in short-term fading. The model adopts a modified version of MDC technique for encoding the layer blocks in the application layer and superposition coding for multi-resolution modulation/demodulation in the MAC and PHY layers to solve multiuser channel diversity problem. Additionally, in the application layer, Reed-Solomon coding for the encoded blocks of the layers is applied for the recovery of the partially received packets due to temporary wireless channel fluctuations. As shown in the results of the simulations, a better video quality is provided compared to a model that only utilizes superposition coding in the PHY layer such as the model in [4].

It should be noted that both of the models in [4] and [12] primarily aim robustness, and instead of providing the same video quality to every user in the network, they serve the users with a low, but acceptable quality at unexpected fading conditions. This would probably bring out the problem in marketing of IPTV service that people who can only be served at low quality video most of the time will be unwilling to pay the same amount of money with those receiving high quality most of the time.

In [27, 28], similar utility-based resource allocation schemes are considered for layer-encoded IPTV multicast in WiMAX networks. In the models proposed, each video frame of an IPTV channel is encoded into different quality layers consisting of a base quality layer and multiple enhancement quality layers. The decoding of the base layer alone provides the basic acceptable video quality and the additional decoding of the enhancement layers progressively increase the video quality. The more enhancement layers are received by the user, the better the video quality becomes. The base layer video is transmitted using the highest applicable modulation scheme for all users in order to assure that all the users receive the base video quality and the enhancement layers are modulated by higher capacity modulation scheme(s). Hence, the users with perfect channel quality are able to achieve the finest quality video by receiving all the enhancement layers. Given the utility functions for different layers of video and the data rates for the users in multicast groups, the algorithms find a sub-optimal allocation in polynomial time, which is important for a real-time system considering the NP-hard complexity of the problem. These papers show that the use of layer encoding results in better overall utilization compared to single layer programs, and therefore layer encoding is suggested in WiMAX networks. Although proposed approaches are effectively solves the multiuser channel diversity problem, they do not provide any solution to the aforementioned problem where some users always receive low quality video.

Another scheduling scheme for real-time layer encoded video multicast in WiMAX networks is described in [29]. Similar to other approaches that adopts layer encoded video streaming, the video bitstream is encoded into a base layer and multiple enhancement layers. In this model, the base layer video bitstream and the enhancement layers are also transmitted separately and in order as in [27, 28]. Following the transmission of the base layer video data, for the scheduling of the enhancement layer data, a greedy algorithm is proposed for selecting the modulation schemes to be applied. The main selection factor for the greedy algorithm is chosen as allocating the resources to the multicast groups for which the spectral utilization is maximized. The model aims fairness in resource allocation via a proportional scheme which maximizes the sum of the logarithm of the data rates. The results of the simulations show that the proposed greedy algorithm performs close to the optimal allocation scheme. Considering the complexity of this modulation selection problem and the limited computational time, a greedy algorithm is preferred.

In [15], a cooperative error recovery framework for IPTV Service over WiMAX networks is proposed. The proposed model is also designed for the PMP mode operation and aims at achieving a resource-efficient, robust IPTV service via the cooperation of the nodes for the recovery from the packet losses. A two phase transmission technique is considered. In the first transmission phase, the transmissions of the BS takes place. The IPTV content is multicast to the multicast group using a modulation scheme which ensures that certain percentage of users is able to receive the data successfully. Following this, in order to avoid unicast retransmission by the BS in case of packet losses, a cooperative second phase is considered for the recovery of the packet losses. In this second transmission phase, the users who fail to receive the transmission of the BS in the first phase are allowed to recover the packet losses via communicating with the users who receive the data successfully in the first phase. Based on the feedbacks on the multicast session from the users after the first phase, the algorithm determines the cooperation groups and assigns the cooperative transmitters to the receivers so that the network resources are utilized most efficiently and the session throughput is maximized. Meanwhile, the minimum service quality requirements of IPTV is assured. According to the simulation results provided, the proposed model performs significantly better in error recovery compared to a unicast transmission scenario.

Similarly in [16], a cooperative multicast scheduling scheme for IPTV Service over WiMAX networks is proposed. This paper address the same problem of multiuser channel diversity problem for the multicast groups and proposes a similar two-phase cooperative approach to distribute the IPTV content to the multicast groups effectively. Additionally, the paper addressed the multi-group diversity issue and a probable fairness problem due to this overall channel quality differences between multicast groups. Considering a scheduling scheme in which the allocations are done based on the sum of the channel conditions of all group members, the multicast groups which have good overall channel conditions may be favored and are more likely to be served primarily. The model proposes a selection criterion based on averaging and normalizing the long-term channel condition to solve this problem. The results of the models support the view that utilizing a two-phase high data rate transmission can be more spectral efficient and achieve higher throughput than a one phase direct low data rate transmission.

Indeed, these cooperative approaches in [15] and [16] are similar to the standard two-hop WiMAX Mesh mode operation in the sense that some SSs are utilized to relay transmissions in favor of the others who suffer from bad channel conditions in an ad-hoc manner. A basic problem with these models is the variation of data rates for the group. The cooperation is done only within the multicast group. Considering a case in which all the group members have relatively low-data rate connections to the BS, the throughput of the system is inevitably degraded, and the packet delays may easily violate the acceptable bounds. Similarly, the cooperation may have to be done over low data rate links due to positioning of the nodes within the multicast group, and the delay bounds may be exceeded. At this point, an approach with a fixed multicast tree similar to WISDoM-SD can be utilized to achieve less deviant data rates and thereby stabilize packet delays. Additionally, instead of reserved cooperation periods for single multicast groups, different multicast groups may cooperate simultaneously for available conditions. Thereby, the contribution of the parallel transmissions can be significantly increased. In WISDoM-SD, a common relaying phase (the counterpart of cooperation phases in [15] and [16]), which includes the whole network (with relayers of different multicast groups), is considered.

In [31], a centralized resource allocation scheme for multimedia traffic in WiMAX Mesh networks is proposed. The scheme aims at efficient distribution of multimedia traffic via utilizing an enhanced frame registry tree scheduler, E-FRTS. Instead of processing requirements and creating the frame schedule at the beginning of each frame, the data packets are scheduled to be transmitted in the last time frame before the deadline of the packet, and thereby the computational time required for frame scheduling is reduced. The frame scheduling process of the scheduler is based on the enhanced frame registry tree in which the bandwidth requests are stored in an organized way according to the scheduler's decisions to be used in frame scheduling. One of the most crucial results of the simulations show that there is a rapid increase in the delays for networks with more than two hops, which makes it infeasible for the system to support delay-sensitive applications like IPTV.

In [32], an adaptive demand-driven multicast routing scheme for multi-hop wireless ad-hoc networks is proposed. The protocol considers sending of the multicast packets over shortest-delay paths from the sender to the receiver multicast group. No static routes are assigned for the packets while doing this and the packets may follow any branch in the multicast forwarding tree. The proposed scheme aims at reducing the periodic components to maintain core routing functionalities. In the proposed protocol, instead of utilizing periodic network control methods, the traffic patterns of the applications are monitored, and based on this monitoring the link breaks or the inactivities of the links are detected. The detection of link breaks or inactivities are generally based on significant deviations in the traffic patterns of the applications. Upon detection of such deviations, these routes are pruned. The proposed protocol is designed to work also in the existence of unicast protocols. However, information sharing is not considered due to modularity and portability issues.

In [33], Tao *et al.* propose a concurrent transmission algorithm for throughput enhancement in fixed WiMAX Mesh networks via spatial resource reuse. The routing tree construction scheme plays an important role to exploit the contribution of concurrent transmissions for the performance of the network. Based on the interference information, which is globally known by the users, the newly joining SS selects one of its neighbors whose transmission causes the least interference on other links in the network as its sponsor node, and joins the network over this node. As a result, a routing tree is constructed so that concurrent transmissions are favored. For the scheduling phase of the model, the transmission occurs in the same node order defined in standard MSH-CSCH message, which includes the routing tree in a single link list and the nodes are ordered according to the hop count. So, in the uplink/downlink, the nodes with highest/lowest hop count transmit first, and then transmissions of the nodes for the lower/higher hop count occur. Processing the requests of the nodes in the order described, parallel transmissions are scheduled for the cases in which the required Signal to Interference Noise Ratio (SINR) constraints are regarded (i.e., no collusion occurs).

Similarly in [34], another interference-aware WiMAX Mesh model is proposed. Instead of only looking at the interference of the sponsor on the other links as in [33], the whole multi-hop route interference is considered for an interference-aware routing tree construction. In order to select the routes, a blocking metric is used which simply indicates the number of blocked nodes by all intermediate nodes involved in the route from the BS to the SS in scope. The routes for which the interference to other nodes is minimized (i.e., the minimum blocking metric) are added to the routing tree. For the scheduling of the requests, the links with the highest demands are scheduled first. Meanwhile, the number of concurrent transmissions are maximized regarding the SINR constraints.

Both of the models proposed in [33,34] aim at maximizing the number of concurrent transmissions, and thereby achieve higher spectral utilization and higher throughput. The results of the simulations depict the fact that the routing tree construction plays a vital role for the network performance and an approach addressing this issue may result in significant performance increase compared to a default random scheme.

In [35], a stability-oriented multicast approach under dynamic user behavior is proposed. The paper addresses the control messaging overhead in the delivery network due to the changes in the multicast routing tree incurred by random TV channel switching of the users. An algorithm is proposed to find a stable multicast tree so that less grafting/pruning is required. The authors consider a construction approach in which combination of only high leaving probability paths should be avoided, and a low leaving probability path should be assigned to each edge so that edge pruning due to absence of the paths is minimized. Meanwhile, it is noted that in order to maintain the stability, the paths should not be oversized and the length of tree should be kept as compact as possible. The results of the simulations show that in general less branch pruning is required, compared to a minimum spanning tree approach.

In [36], considering a limited energy resource for the nodes of the network, an energy efficient multicasting solution for general ad-hoc networks is proposed. An iterative dynamic multicast tree reconstruction scheme is utilized to maximize power savings for multicasting. Different from of the usual minimum energy multicasting approaches, in this scheme the minimization of the multicast tree energy is addressed instead of the general broadcast tree. Additionally, in case of a new node entry, the multicast tree is reconstructed instead of simple expansion of the tree. One of the problems that may arise with this solution is the global reconstruction process in case of a new entry especially for large networks. Although it may result in better efficiency for networks with small number of nodes, the time required for the reconstruction may be problematic for delay intolerant applications for large networks, and further precautions may be required to sustain the application.

A Dynamic Station Selection (DSS) scheme to maximize the number of recipients in IEEE 802.16j WiMAX Relay Networks [41], which works with a similar relay principle to the WiMAX Mesh mode, is proposed in [37]. In addition to the SS in the

WiMAX PMP mode, there are fixed relay stations (RSs), which conduct transmissions of the SSs to/from the BS similar to the MSS in the WiMAX Mesh mode. Beginning from a network with only the BS and RSs, round by round, an unserved SS is selected from the set of unserved SSs and included into the service so that the allocation utility (i.e., the ratio of incrementally included SSs to the incrementally allocated sources) is maximized. The algorithm stops when either the link capacity limit is reached or there are no unserved SSs left. Considering the NP-hard complexity of the multicast recipient maximization problem, the proposed solution offers a polynomial-time computational complexity. It is shown that the algorithm achieve results close to the optimal solution. Besides the fact that the deployment of a relay station is nearly as costly as to that of a base station (which pushes people to adopt multiple micro-cell approaches), the main problem with the usage of the fixed relay stations is the lack of adaptability to changing environment. Moreover, the deployment of a relay station scheme as in IEEE 802.16j obviously requires a preliminary work for optimal placement of the relay stations according to the distribution of the users in a region.

Besides the works listed above, there are also other works that approach the subject of IPTV streaming over WiMAX from another perspective as in [42]. Considering the exhaustion of the IPv4 address pool and the general adaptation processes towards the IPv6-based networks, the authors focus on the issues related with the deployment of IPv6-based WiMAX networks as a part of converged networks. The paper provides a testbed evaluation of IPTV video streaming performance for heterogenous converged networks with IPv6 and Mobile IPv6 (MIPv6) handovers. The results of the paper show that there are only a few problems for MIPv6 handovers between converging heterogenous access networks. It can be concluded that the MIPv6 handover processes for converged networks need further studies to maximize the operational performance of other networks for WiMAX.

There are also some studies in the literature that completely focus on Mobile video streaming over WiMAX [43, 44]. A similar utility based layer encoded video streaming scheme to [27, 28] is proposed for the video multicasting in mobile WiMAX networks in [43]. The model adopts the isolated region coding [45] technique in the application layer and the video is encoded into a high priority core stream and a lower priority margin stream. The model aims at maximizing the utility which is based on the ratio of the acquired satisfaction and the required bandwidth. The results of the simulations show that compared to single layer programs the isolated region coding approach results in efficient allocation of resources and a higher total utilization.

Another study, which focuses on video streaming over Mobile IPTV over WiMAX networks, is [44]. An adaptive hybrid transmission scheme, which utilizes both the unicast and multi-channel multicast mechanisms, is proposed to minimize service blocking probability. In the proposed scheme, the on-demand content is divided into two groups as popular highly requested contents and others. For the transmission of the highly requested content, multicasting is utilized. The other contents are sent via unicasting. The algorithm adaptively finds the optimal channel assignments for multicasting and unicasting in order to minimize the service blocking probability.

Security in IPTV systems have also been studied in the literature and these studies cover various issues such as Digital Rights Management (DRM) and multicast key generation/management protocols in [46–48].

A design of a digital copyright protection protocol for IPTV, IPTVDRM, is proposed in [46]. Besides meeting the basic requirements of digital copyright protection, the proposed protocol addresses the attacks against IPTV protocol. Additionally, utilizing a gateway web service with a copyright center as a trusted third party, it insures fairness between the providers of the digital content and the customers.

In [47], a multicast key management protocol for IPTV is presented. The proposed protocol utilizes a hierarchical server tree, which is composed of a main authentication server and sub-authentication servers to handle the key management. There are two encryption keys used for communication in the network. One key is generated by the main authentication server to be used for network-wide group communication/messaging and another key is generated by the sub-authentication server to be used for sub-group (i.e., local) communication/messaging.

Considering the problems due to fast channel switching (i.e., zapping) of users, an alternative secure multicast solution for real-time IPTV services is proposed in [48]. In the proposed scheme, the concept of TV channel bundles, which are composed of several channels, is considered for a more realistic approach. Accordingly, a centralized secure group communication scheme with two types of encryption keys (i.e., besides the bundle key, a data key for each channel) is proposed. The main aim of the proposed scheme is basically to reduce signaling overhead in channel zapping scenarios. The results of the simulations show that utilizing the proposed scheme does not cause any significant timing problems for the group join operations, and TV channel switching delays are comparable to the traditional analog TV over cable.

4. WISDoM-SD

Considering the multicast and relaying features of WiMAX, we propose a new model, named Wireless IPTV Service Distribution over Mesh Mode benefiting from Space Diversity (WISDoM-SD), based on the standard IEEE 802.16 Mesh operating mode. Additionally, in order to improve the performance of the basic Mesh mode operation, some amendments are proposed. The key features of our model can be listed as follows:

- Relaying over high capacity links in order to provide service to users who are unable to establish connection to the BS using a high capacity modulation.
- Avoiding retransmission of the same data for an IPTV channel using different modulation schemes and multicasting the data only once using a chosen high capacity modulation scheme.
- Utilizing parallel transmissions for suitable conditions in which SNR values for simultaneous transmissions are preserved.

One of the primary aims in using the Mesh mode operation is to distribute IPTV service to the subscribers who have difficulty in connecting to the BS directly. Relaying feature of the Mesh mode simply removes the requirement of direct connection to the BS. Instead, the subscribers have the ability to connect to their neighboring subscribers and receive service over them.

Secondly, spectral efficiency of the model is considered. As mentioned before, multicasting plays a major role for applications like IPTV in which delivery of the same data to multiple users is required. Via multicasting, video bitstreams of a TV channel can be delivered simultaneously to multiple users. Thereby, significant amount of bandwidth can be saved compared to unicast schemes. However, in a typical urban/sub-urban scheme, users may experience significantly varying channel conditions. Hence, these users are enforced to use available modulation schemes according to their received signal quality.

Conventionally, separate data streams are utilized for broadcasting a requested TV channel for each type of modulation used by subscribers. As a result, the same data for a single TV channel is broadcast multiple times according to the requested modulation-coding schemes in the multicast group. Consequently, the spectral efficiency of the system is significantly degraded due to the retransmissions, and the capacity of the network is used inefficiently.

As a straightforward solution, in order to solve the multiuser channel diversity problem and primarily avoid retransmissions, the highest applicable modulation scheme (i.e., a robust modulation scheme) for every user who requests the same channel can be utilized to send the video stream. Compared to the conventional methods, even good quality connections have to use the chosen low capacity modulation, and every user receives the transmission for a TV channel during the same time period. As a result, some bandwidth savings can be achieved. However, it should be noted that the spectral density of the highest applicable modulation scheme for every user is low and many transmission slots are required to deliver the TV channel data.

The typical data rate requirement for an HDTV channel is around 6 Mbps as shown in Table 2.2. Therefore, it is of vital importance to establish connections using high capacity modulation schemes. Unfortunately, it is generally hard to establish a high capacity connection to the BS, especially in rural areas. Physical proximity to the BS does not guarantee a good quality connection. There may even be cases where a user may fail to establish any connection to the BS at all.

As shown in [49], the latency values increase dramatically for connections with more than two hops to the BS. Therefore, it seems impractical to sustain applications like IPTV, which have strict delay constraints. Although there are no limitations for the number of hops to the BS in the WiMAX Mesh mode, at most two-hop connections to the BS are allowed in our proposed model due to delay-sensitive nature of IPTV application.

Taking these approaches into consideration, instead of utilizing a low capacity connection at single hop, we propose a two-hop Mesh mode operation based on relaying over only high capacity links, which provide better spectral efficiency compared to the previous solutions. Although some subscribers may not able to connect to the BS using high capacity modulation and coding schemes, it is very likely that they have some neighbors who can connect to the BS using a high capacity modulation and coding scheme. In this respect, even though some subscribers are able to connect to the BS using a low capacity modulation scheme, they prefer to connect to relaying neighbor stations and receive service over them.

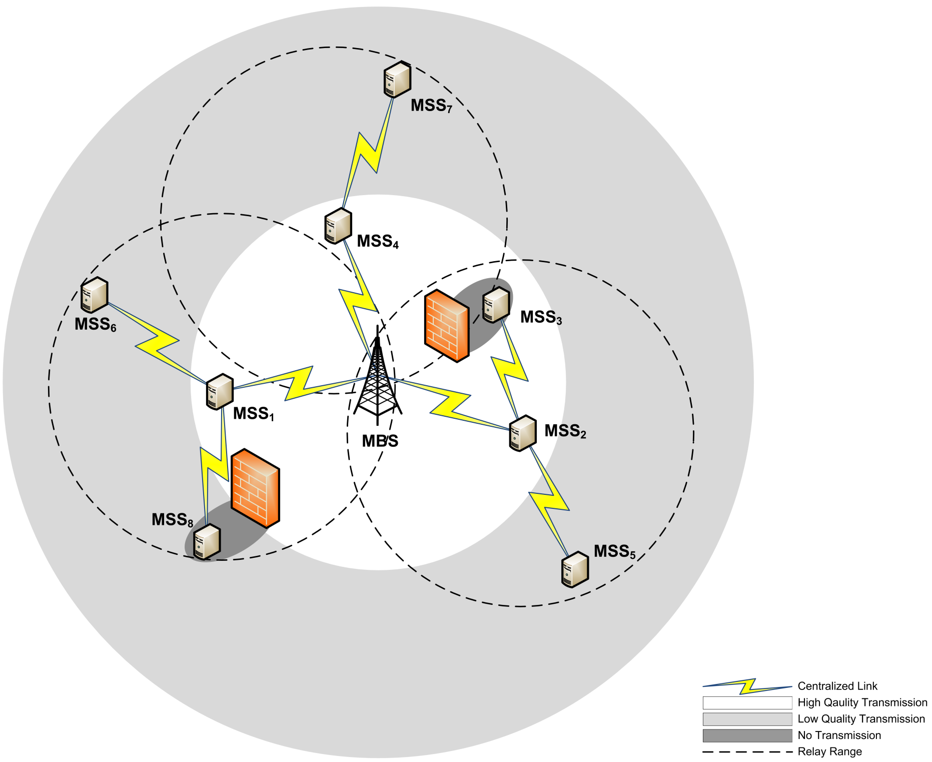

Figure 4.1. A sample relaying scenario.

A sample relaying scenario with eight subscriber stations is shown in Figure 4.1. In this scenario, three stations, MSS_1, MSS_2, and MSS_4, are placed in the white zone indicating that the nodes inside this zone are able to connect to the BS using high capacity modulation schemes, such as $64-QAM$, in good channel conditions. Besides these stations, another group of three stations, MSS_5, MSS_6, and MSS_7, are placed in the light gray zone outside the white zone. Due to the path loss attenuation, these stations have no chance to connect to the BS using a high capacity modulation coding scheme even at LOS condition. Therefore, the usage of more robust (i.e., less spectral efficient) modulation and coding schemes is required for these stations. Additionally, there are some dark gray zones shown in the figure. The dark gray zones simply indicate complete blockage of signals from the BS due to some environmental obstacles. As a result, the nodes which reside in these dark gray zones have no chance to connect to the BS, even using the most robust (and lowest capacity) modulation scheme. MSS_3 and MSS_8 are placed in these dark gray zones in our example scenario. As can be observed from Figure 4.1, physical proximity does not necessarily guarantee high capacity connection. Although MSS_3 is positioned closer to the BS compared to other stations, its signal quality is degraded significantly by environmental obstacles on the path to the BS.

Since MSS1, MSS2, and MSS4 are able to connect to the BS using a high capacity modulation scheme, they are the potential parent stations (i.e., relayers) in the network. The ranges that these stations support for relaying (i.e., high capacity connection range) are shown by dashed lines. Accordingly, MSS_8 and MSS_3 are connected to BS at two hops over their neighboring stations MSS_1 and MSS_2, respectively, utilizing the Mesh mode operation. Although MSS5, MSS6, and MSS7 are able to connect to the BS directly, these stations can not use high capacity modulation and coding schemes due to the path loss attenuation. Nevertheless, they are able to establish connection to the stations in the white zone (i.e., the stations who can transmit to the BS using high capacity modulation schemes) using a high capacity modulation scheme. For this reason, they prefer to connect to these stations instead of the BS. In Figure 4.1, the centralized links are shown with arrow symbols.

Different from the cooperative schemes [15, 16] in the literature, we consider relaying over the centralized links of the WiMAX Mesh network. Thereby, we aim at eliminating the problems with [15,16] in which all members of a multicast group may be positioned in a condition that enforces the usage of low data-rate links for the multicast group. In WISDoM-SD, even if a one-hop subscriber station is not a member of the multicast group, it buffers and relays transmissions for its children subscriber stations. Similarly, WISDoM-SD eliminates the condition in [15, 16] in which the cooperation between members of the multicast group may be carried over low data rate links.

Additionally, in order to improve the performance of the model, parallel transmissions are considered for possible conditions, benefiting from the spatial diversity. Conserving the required SNRs for the chosen modulation and coding schemes, different subscriber stations can transmit simultaneously in distinct regions of the network.

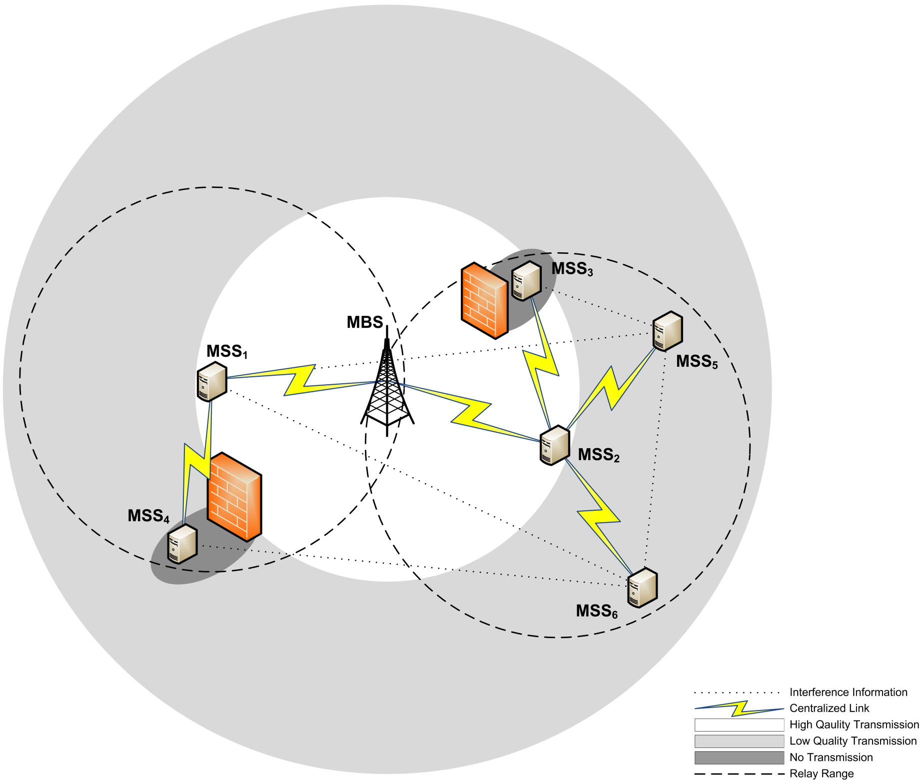

Figure 4.2. A sample parallel transmission scenario.

A sample parallel transmission scenario with two one-hop stations, MSS_1 and MSS_2, and four two-hop subscriber stations from MSS_3-MSS_6 is shown in Figure 4.2. Similar to the previous figures, the ranges that one-hop stations support for relaying are shown by dashed lines. In this scenario, MSS_1 relays the transmissions for MSS_4, and MSS_2 relays the transmissions for MSS_3, MSS_5, and MSS_6. Besides the centralized links which are shown with yellow arrows, the dotted lines in this figure indicate that the nodes are in each others' interference range.

As can be observed from Figure 4.2, the stations are placed such that all the two-hop subscriber stations, except MSS_3, are inside the interference range of MSS_1. Therefore, while MSS_2 is transmitting for MSS_5 or MSS_6, if MSS_1 attempts to make a transmission to MSS_4 during the same time period, the transmission from MSS_2 to MSS_5 or MSS_6 are interfered by the transmission of MSS_1. In this respect, the only available station, which is able to receive a transmission successfully while MSS_1 is transmitting, is MSS_3. Similarly, the transmissions from MSS_2 are received by most of the neighbors, except MSS_4. Therefore, MSS_4 can receive the transmissions from MSS_1 successfully while MSS_2 is transmitting to MSS_3. Considering this scenario, the transmissions from MSS_1 to MSS_4 and from MSS_2 to MSS_3 can be scheduled for the same time period and carried out simultaneously.

4.1. Multicast Tree Construction

In the WiMAX Mesh mode, simply the neighbor with the highest SNR value is chosen as the parent node. However, for models that consider parallel transmissions (including WISDoM-SD), the routing tree should be carefully designed in order to exploit the spatial diversity. As shown in [33, 34], the multicast tree construction schemes have vital importance in improving the performance of the network. Based on a routing tree, which exploits the spatial diversity, the number of parallel transmissions may be increased so that significant bandwidth savings can be achieved.

Considering the changing requests of the users, always achieving the maximum efficiency is a challenging problem, and it requires reconstruction of the links in real time. Therefore, some general heuristics are required to achieve this goal. In this respect, WISDoM-SD proposes a parallel transmission opportunity metric to be used for the selection of the parent nodes (i.e., construction of the multicast tree links).

In the parent selection process, if a node is able connect to the BS directly using a high capacity modulation and coding scheme, it selects the BS as parent node and receives service directly from the BS. Otherwise, the node searches for neighboring candidate parent nodes that can relay transmissions of it. At this point, the candidate parent nodes are ranked according to a parallel transmission support metric which indicates the number of parallel transmission opportunities they support as parent nodes. To do this ranking, the transmission opportunities with all of the two-hop nodes in the network is checked out one by one. If the received power from the parent node of a two-hop node is below the noise threshold and if the candidate parent node does not cause interference on the the two-hop node either, we may conclude that there is a parallel transmission opportunity and this counts as a score for our metric. Traversing all of the two-hop nodes in the network, a total parallel transmission opportunity score is calculated for the candidate parent nodes. The highest scorer is selected as the parent node, and the multicast tree link is established with the parent node.

The pseudo-code of the complete parent selection process is shown in Figure 4.3:

```
if the SS can connect to the BS using the selected modulation directly,
    Connect directly to the BS
Otherwise,
    For each candidate parent node,
        Traverse all of the two-hop nodes in the network,
            If parallel transmission is possible,
                Increment the score of the candidate parent node
    Select the node with the highest score as the parent node
    Construct the multicast tree link with the parent node
```

Figure 4.3. The pseudo-code of the parent selection process.

A sample multicast tree construction scenario is shown in Figure 4.4. In this scenario, there are three one-hop stations, MSS_1, MSS_2, and MSS_3 and two two-hop subscriber stations, MSS_4 and MSS_5. The ranges that one-hop stations support for relaying are shown by dashed lines. As shown in the figure, MSS_5 resides in the relaying range of the MSS_3 and is connected directly to this station since there is no alternative. On the other hand, MSS_4 resides in the relaying range of two one-hop stations, MSS_1 and MSS_2, and thereby has a chance to make a choice between these candidate parent nodes.

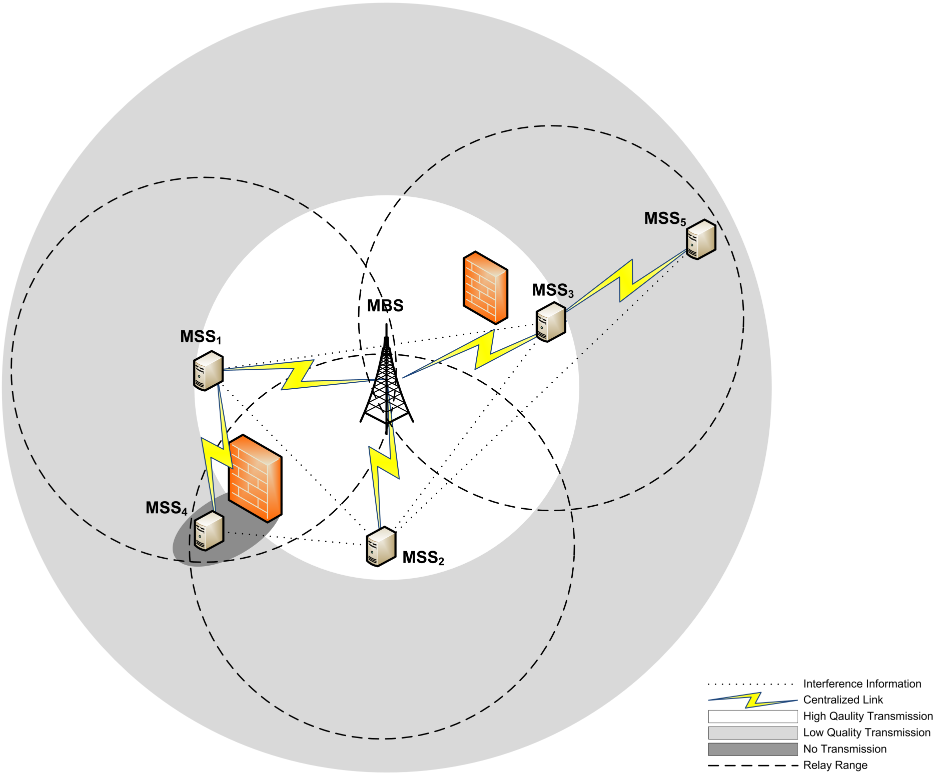

Figure 4.4. A sample multicast tree construction scenario.

The interference between the nodes of the network is shown by the dotted lines in Figure 4.4. If any two stations are within the interference range of each other, there is a dotted line between these stations. According to this interference information, the transmissions from MSS_3 to MSS_5 do not cause significant interference on MSS_4. In addition, the transmission from the MSS_3 to MSS_5 is interfered by transmissions of MSS_2 during the same time period. Nevertheless, a simultaneous transmission from MSS_1 does not cause significant interference on MSS_5. As a result, MSS_1 has higher chance for parallel transmissions and therefore it is selected as the parent node for MSS_4 according to our parent selection algorithm.

4.2. Base Station Scheduler

In the WiMAX Mesh mode, the BS scheduler is not defined and it is left as an open subject. Scheduling is also another fundamental part of our model. Indeed, it is the complementary part of the multicast tree construction scheme which tries to maximize parallel transmission opportunities. These opportunities are exploited by the scheduler in order to maximize the performance of the system.

In WISDoM-SD, we aim providing same service quality (i.e., same interframe delays) amongst all users, independent of the physical proximity to the BS. In other words, we assure that both one hop SSs and two hop SSs experience the same interframe delays.

Scheduling is made on scheduling round basis in which a single IPTV data frame of the requested TV channel is distributed to the users. A scheduling round basically consists of two phases: one phase for the transmissions of the BS and a second phase for the transmissions of the parent nodes, following the first phase as shown in Figure 4.5. Since the transmissions in WISDoM-SD is done on WiMAX frame basis, the scheduling process runs as long as there are empty minislots in a frame (i.e., number of minislots scheduled < 256). However, if a phase is not finished at the end of a frame (i.e., there are no empty minislots left to be used for scheduling), the phase continues in the following frame(s) until it is finished.

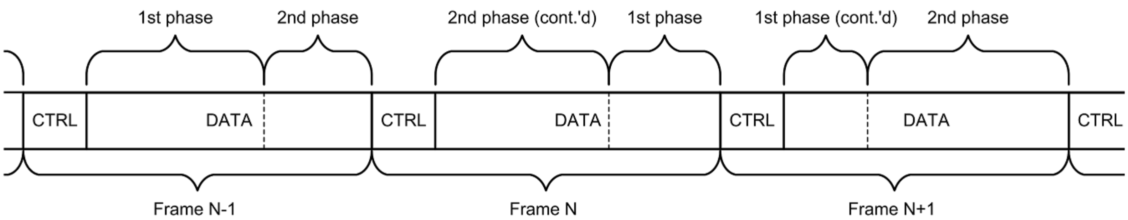

Figure 4.5. Scheduling phases.

In the first phase, the BS transmits frames of all TV channels requested by all one-hop and two-hop stations in the network. During this first phase, all one-hop stations receive a frame of the TV channel they are subscribed to. Meanwhile, the nodes that are supposed to relay for two-hop stations, buffer the frame packets of the TV channels to which their children are subscribed. The transmissions from the BS are straightforward. The requested TV channels are broadcasted sequentially by the BS. During the transmissions of the BS, no other simultaneous transmission occurs.

Following the transmissions of the BS, a new phase for relaying transmissions starts. In this second phase, the one-hop stations, to whom some two-hop stations connected, transmit the frames of TV channels requested by these stations. The ordering and the number of combinations of these requests should be determined for the optimal solution. Yet, the computational complexity for such a computation is really high. Indeed, it is very similar to the knapsack problem in the literature, which is NP-hard to compute. Therefore, some heuristics are applied in order to reduce computational complexity and a suboptimal result is achieved.

For the scheduling of this second phase requests, we use a priority metric based on the number of conflicts between requests that do not allow parallel transmissions. For each of the requests, the number of conflicts with the remaining requests in the list is calculated. While finding the conflicts, the requests from the same parent node are excluded since they have no chance to be scheduled for the same minislot. The requests that have most conflicts with the remaining requests (i.e., the lowest chance to be transmitted parallel) are scheduled at first hand. Since the size of the list at the beginning is at maximum, they are more likely to be involved in parallel transmissions. It is important to note that if a TV channel is requested by more than one user from the same parent node, these users are considered as a group and are served simultaneously (i.e., single transmission is made for the group).

For the scheduling process, a request list is kept for the unserved TV channel requests of the SSs. Initially, the list is filled with TV channel requests of all SSs at that moment. In order to meet the latency guarantee, new request are not added until the list is empty. Whenever the list becomes empty, it is refilled with TV channel requests of all SSs.

The pseudo-code for the complete scheduling process is shown in Figure 4.6:

```
Initialize the schedule and reset the minislot #
While (minislot # < 256) (i.e., there are empty minislots to be scheduled)
    If the request list is empty,
        Refill the request list for the new scheduling round
        Group the requests for the same channel from the same parents
    If BS has to transmit,
        Schedule this requests for current minislot
    Else,
        Find the most conflicting request
        Schedule the group of this request for current minislot
        For the rest of the requests,
            Find the most conflicting request
            If parallel transmission is possible,
                Schedule the group of this request for current minislot
    Increment minislot # (i.e., go to next minislot)
```

Figure 4.6. The pseudo-code of the scheduling process.

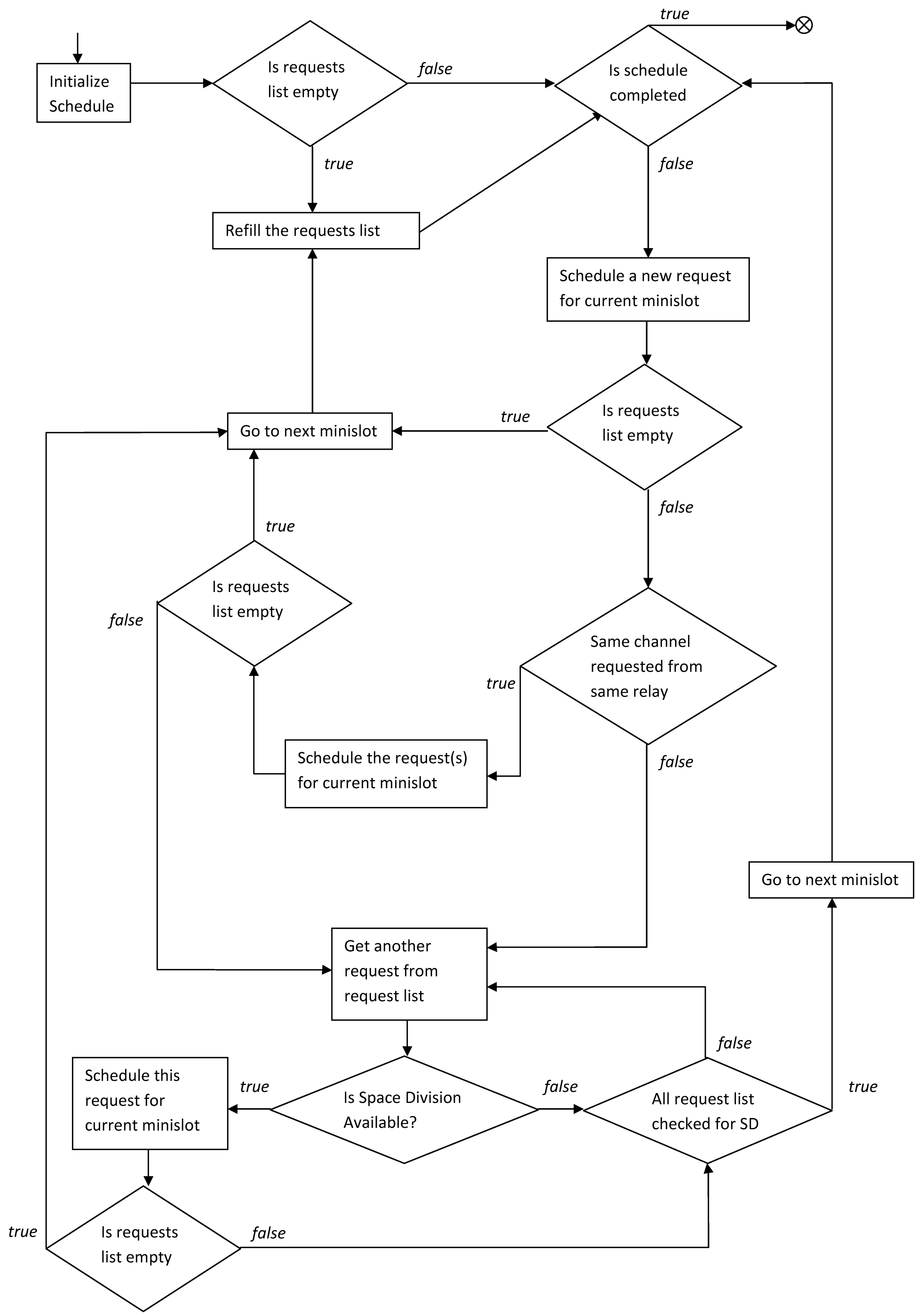

Figure 4.7. BS scheduler flow chart.

5. PERFORMANCE EVALUATION

In this thesis, the standard WiMAX Mesh mode of the IEEE 802.16 and the WISDoM-SD model are analyzed and compared over a set of simulations. Specifically, the performance of the MAC OSI Layer is analyzed. The process models for both MAC layers are implemented and simulated using the OPNET Modeler 14.5.

5.1. Simulation Setup

The simulation process can be divided into two phases as network setup (deployment and link establishment) phase and simulation run phase.

For the deployment of the obstacle and node objects, we consider a range from the BS in which $64-QAM$ modulation can be applied. The frequency of operation is chosen as 5 GHz and 20 MHz bandwidth is considered. Minimum performance requirements for 20 MHz OFDMA scheme defined in the WiMAX standard IEEE 802.16d are shown in Table 5.1

Table 5.1. Minimum Performance Requirements for 20 MHz OFDMA [18].

Modulation	**Coding Rate**	**Required SNR**
QPSK	1/2	≤-79 dBm
16-QAM	1/2	≤-72 dBm
16-QAM	3/4	≤-69 dBm
64-QAM	2/3	≤-65 dBm
64-QAM	5/6	

Typical values are considered for the transmission properties of transmitter and receiver antennas. Both transmitter and receiver antennas are assumed to be omnidirectional and have 24 dBm total gains, and the transmission power is assumed to be 23 dBi as shown in Table 5.2. Considering a free path loss propagation for the given power parameters in Table 5.2 and a 18 dB fade margin, the range for the usage of $64 - QAM$ modulation (with coding rate 2/3) is calculated as 3.8 km from the BS.

Table 5.2. Wireless Channel Parameters.

Parameter Name	**Parameter Value**
Transmitter Frequency	5 GHz
Transmitter Antenna Gain	24 dBm
Receiver Antenna Gain	24 dBm
Transmit Power	23 dBi
Penetration Loss	20 dB
Fading Factor	18 dB
m-value	2.0

First the obstacles and then the nodes are uniformly deployed in 3.8 km range from the BS. The total number of obstacles and nodes are defined by the topology parameters *Obstacle Count* and *Node Count* in Table 5.3, respectively. The obstacles have varying sizes from *Minimum Obstacle Length* to *Maximum Obstacle Length*, which are also defined in Table 5.3.

Table 5.3. Topology Parameters.

Parameter Name	**Parameter Value**
Node Count	50 to 300
Obstacle Count	200
Minimum Obstacle Length	25 m
Maximum Obstacle Length	100 m

Following the deployment of the obstacles and the nodes, the average signal powers between the nodes are estimated considering free space loss and obstacle penetration losses (20 dB per obstacle penetration). Finally, the links of the multicast tree are established according to the multicast tree construction scheme described in Section 4.1.

Additionally, for the modeling of the wireless channel, Nakagami-m channel model is used [50]. According to this model, the instantaneous received power is distributed exponentially with the average received power. The m-value for the model is selected as 2.0 as shown in Table 5.2.

The parameters for the WiMAX Mesh Frame are listed in Table 5.4. The frame length is chosen as 20 ms. A frame is composed of 256 minislots for the data subframe and 10 minislots for the control subframe. Additionally, the $64-QAM$ modulation with coding rate 5/6 is considered for data transmission over the centralized links of the network.

Table 5.4. WiMAX Mesh Frame Parameters.

Parameter Name	**Parameter Value**
Frame Length	20 ms
Number of Data Minislots	256 minislots
Number of Control Minislots	10 minislots
Data Subframe Modulation	64-QAM
Data Subframe Coding Rate	5/6

A sample deployment scenario with 100 nodes and 200 obstacles are shown in Figure 5.1. The inner circle shows the theoretical range in which a user can connect to the BS directly using the $64-QAM$ modulation with coding rate 5/6. The outer circle shows the theoretical range for which $64-QAM$ modulation can be used. The obstacles in the area of deployment are shown with black solid lines. The nodes that are able to directly connect to the BS are shown with filled squares and the nodes that are connected to the network in two hops are shown with empty squares. Finally, the nodes, which are unable to connect to the BS at all, are shown with crosses. As can be observed from Figure 5.1, some of the nodes that are placed in the inner circle prefer to receive service over other subscriber stations as a result of degraded SNR values due to penetration through obstacles in the area.

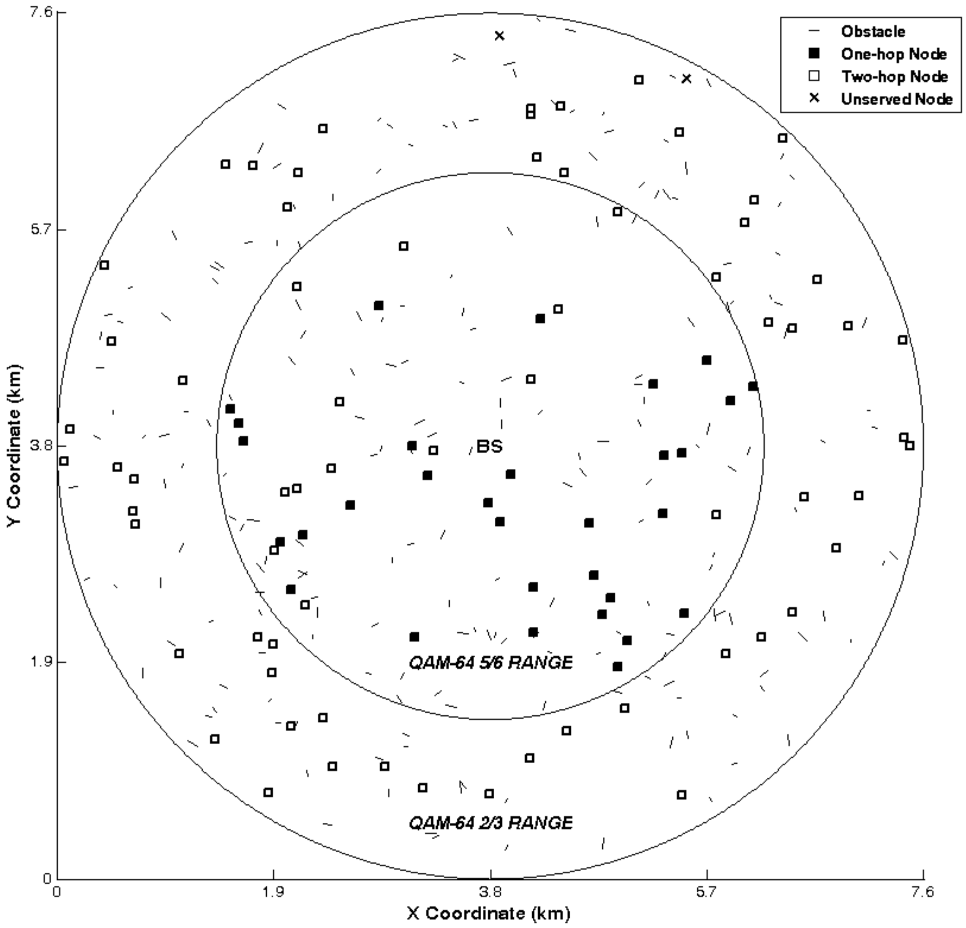

Figure 5.1. A sample deployment scenario with 100 nodes.

The parameters for IPTV service are listed in Table 5.5. *Channel Count* is the total number of available TV channels that a user may request. *Channel Bandwidth* is the bit rate requirement of a typical TV channel. *IPTV Data Frame Length* is the bit length of each frame burst of a TV channel. *Simulation Duration* is the length of network operation in seconds. Since the scheduling is done on scheduling round basis, the system is stabilized in a few WiMAX frames after a change in TV channel requests. Therefore, it is not required to have a long simulation duration and the simulation duration is chosen as ten minutes in this thesis. A subscriber may request a new channel at each time unit according to the value defined by the *Channel Request*

Interval parameter. After this period, a subscriber may stay watching current TV channel or request another TV channel according to the probability defined by the *Probability of Changing Channel* parameter.

Table 5.5. IPTV Parameters.

Parameter Name	**Parameter Value**
IPTV Channel Count	100
IPTV Channel Bandwidth	6 Mbps
IPTV Data Frame Length	300 Kbits
Simulation Duration	600 sec
Channel Request Interval	1 sec
Probability of Changing Channel	0.05

Since the users' TV channel selections greatly influence the load on the system, two scenarios with different TV channel selection characteristics of the users are considered for the evaluation of WiSDoM-SD. In the first scenario, each TV channel is considered to have equal chance of being selected by the users. Accordingly, users' TV channel request process is modeled using a uniform probability distribution function including the whole range of TV channels from TV channel ID 1 to 100. Secondly, a more realistic scenario is considered. Some TV channels are considered to be more popular in public and more likely to be requested compared to other TV channels. Thus, the users' TV channel request process is modeled using a normal probability distribution function in which the TV channels that are more likely to be requested are enumerated around TV channel ID 50 (out of 100 TV channels).

5.2. Simulation Results

Figure 5.2 shows the percentage of the nodes, which are able to receive service (either directly from the BS or over another subscriber station), for cases with various number of nodes deployed in the service area.

In the standard WiMAX PMP mode, nodes must directly connect to the BS and no relaying is allowed. As a result, overall connectivity is not promising. Many subscribers suffer from bad channel conditions and are even unable to maintain the required SNR even for QPSK modulation scheme with coding rate 1/2, the standard modulation scheme for control messaging in the WiMAX Mesh mode [18]. The overall connectivity ratio is just around 67%. In other words, out of 100 nodes only 67 are able to receive service and the rest of the nodes are incapable of connecting to the network and receiving any service.

On the other hand, in the standard WiMAX Mesh mode, subscribers have the ability to connect to other subscribers connected to the network and relay their transmissions over them. As a result, every node is able to receive IPTV service either directly over the BS or over a neighboring subscriber station that is already connected to network.

In order to evaluate the contribution of the proposed amendments to the standard WiMAX Mesh mode independently, a new model, WISDoM, which only considers relaying over only high capacity links without any parallel transmissions (simply the WISDoM-SD model without parallel transmissions), is additionally simulated. In WiSDoM and WISDoM-SD models, overall connectivity ratio is the same, and it is slightly below the standard WiMAX Mesh mode due to the usage of highest capacity modulations. Furthermore, the standard WiMAX Mesh mode connects all subscribers no matter how low the data rate may be whereas WiSDoM and WiSDoM-SD prefer not to connect an IPTV subscriber at all if $64-QAM$ modulation with 5/6 coding rate is not available. There is a trade-off between high capacity modulations and range. Since high SNR is required for high capacity modulation schemes, transmission ranges are inevitably shortened in order to decrease the path loss attenuation. Still benefiting from Mesh mode operation, the number of connected nodes is far greater than the standard WiMAX PMP mode for any cases.

As can be observed from Figure 5.2, for the cases with more than 125 nodes, the connectivity percentage for the proposed models is definitely above 99. However, for the cases with less than 150 nodes, due to sparse deployment in the area, a subscriber

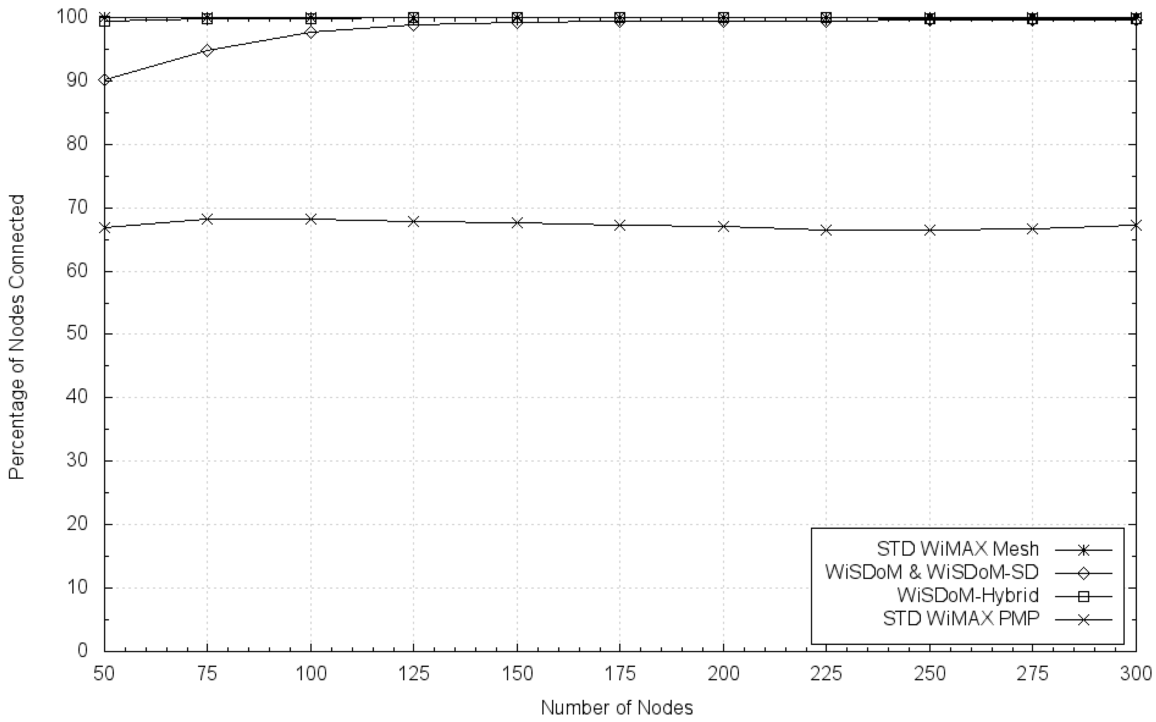

Figure 5.2. Percentage of nodes connected.

station, which is unable to establish a direct connection to the BS, has a low chance to find a parent node to have its transmissions relayed over. As the number of nodes are decreased, the effect of this sparseness becomes more significant and the overall connectivity drops down to 90% for the case with 50 nodes. Although, this result is noticeably better than the results of the WiMAX PMP mode (i.e.,approximately 67%), a hybrid model, WISDoM-Hybrid, is proposed to solve this connectivity issue.

In the WISDoM-Hybrid model, modulation restrictions are relaxed for the subscribers that are unable to connect to the BS or any one-hop SS using highest modulation scheme (i.e., $64 - QAM$ modulation with coding rate 5/6). In this model, the nodes that are left disconnected are allowed to connect to the BS or any RSs by using at least $16 - QAM$ modulation (with coding rate 1/2). As a result, the number of the nodes served is significantly increased for the scenarios with 50, 75 and 100 nodes. The overall connectivity is increased up above 99% and get closer to the standard WiMAX Mesh mode.

For the rest of the thesis, the PMP mode is not considered since it performs far worse than any of the other methods.

5.2.1. Scenario 1: TV Channel Selection with Uniform Distribution

In the first scenario, the probability of a TV channel being requested by a user is considered to be equal for all TV channels. Therefore, users request TV channels according to a uniform probability distribution function including the whole range of TV channels in the system. For this scenario, 30 repetitions have been performed for the cases with different number of nodes deployed. The channel request histogram of a sample subscriber station in this scenario is given in Figure 5.3. As can be observed from the figure, the TV channel requests of a user span the whole range of TV channels from TV channel ID 1 to 100 due to uniform probability distribution function.

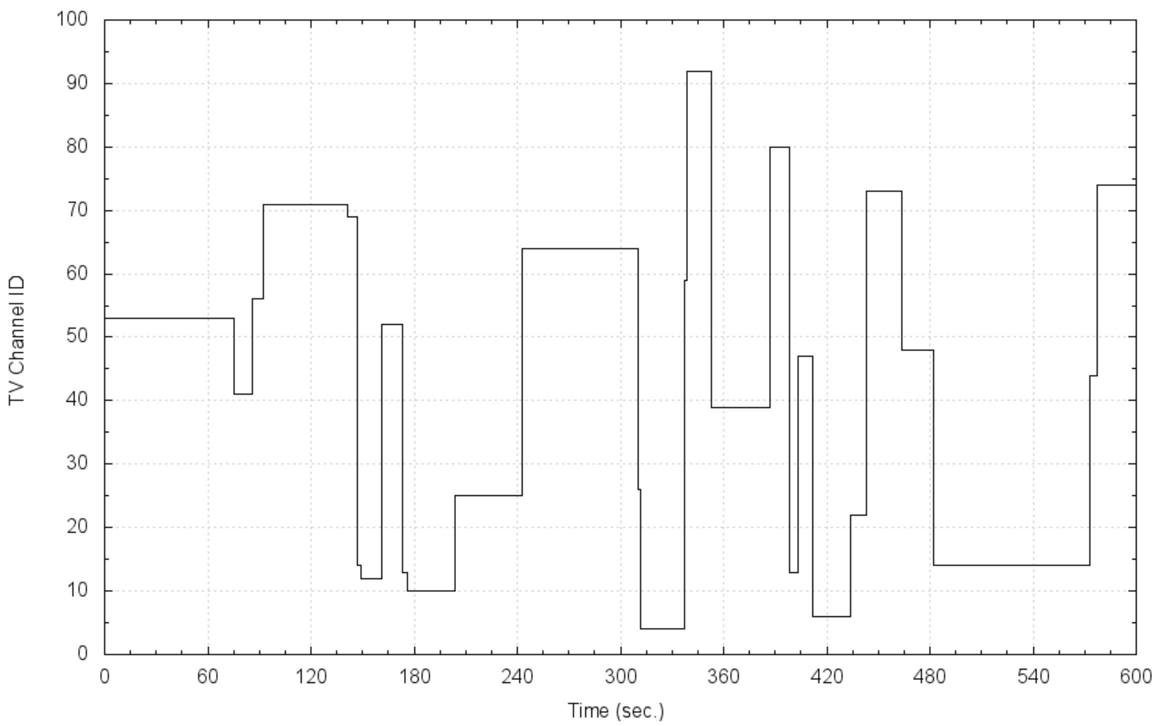

Figure 5.3. Sample TV channel selection histogram of a subscriber station.

The average number of distinct TV channels requested by all users in the network for cases with different numbers of users is shown in Figure 5.4. As expected, due to uniform TV channel selection it is less likely for a TV channel to be requested by

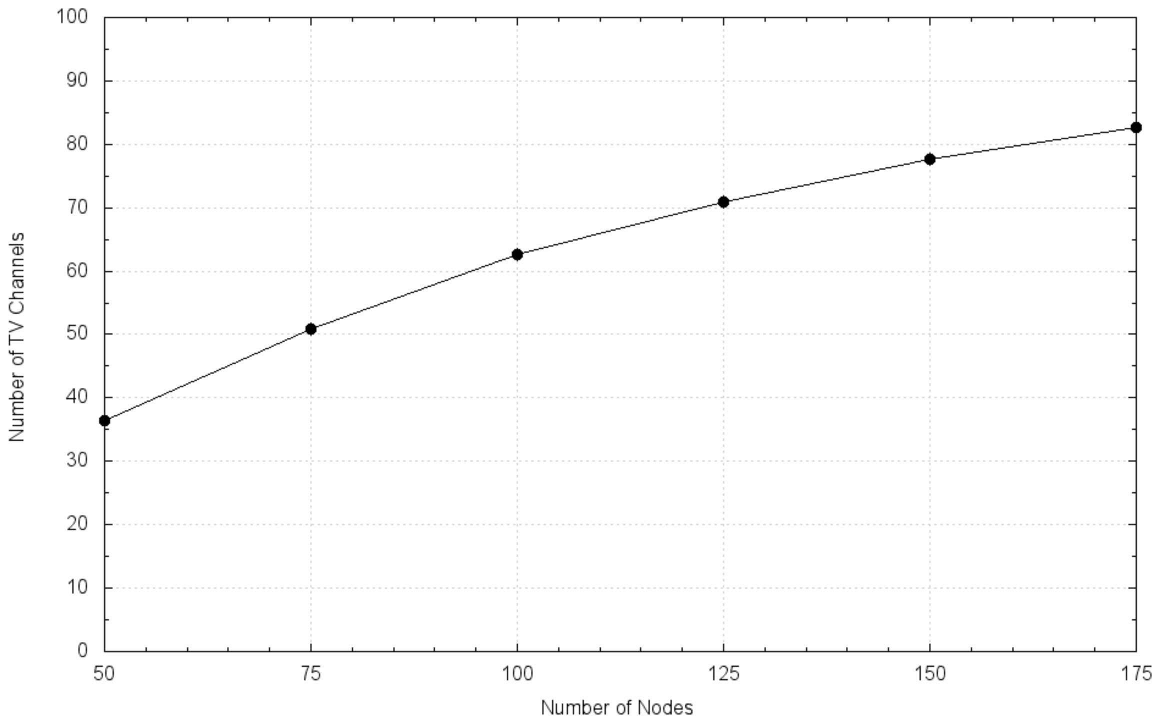

Figure 5.4. Average number of TV channels requested.

multiple subscribers. Therefore, the number of TV channels requested by the users is expected to increase and cover the whole TV channel range as the the number of users in the system increases. Due to 100 TV channel limit, the rate of increase in total number of channels requested decreases as it gets closer to 100 TV channels.

Figure 5.5 shows the average number of IPTV data frame transmissions in a scheduling round. The number of transmissions at first hop represent the number of transmissions required to distribute all the TV channels requested to one-hop subscribers and to the parent nodes for two-hop subscribers. Additionally, the number of transmissions at second hop represent the number of transmissions by the parent nodes. It can be observed that the number of transmissions required at the second hop for two-hop subscribers is very close to the number of transmissions at first hop.

At this point, exploiting space diversity and making parallel transmissions plays an important role in reducing the number of transmissions required for relaying. The number of parallel IPTV data frame transmissions in a scheduling round is shown in

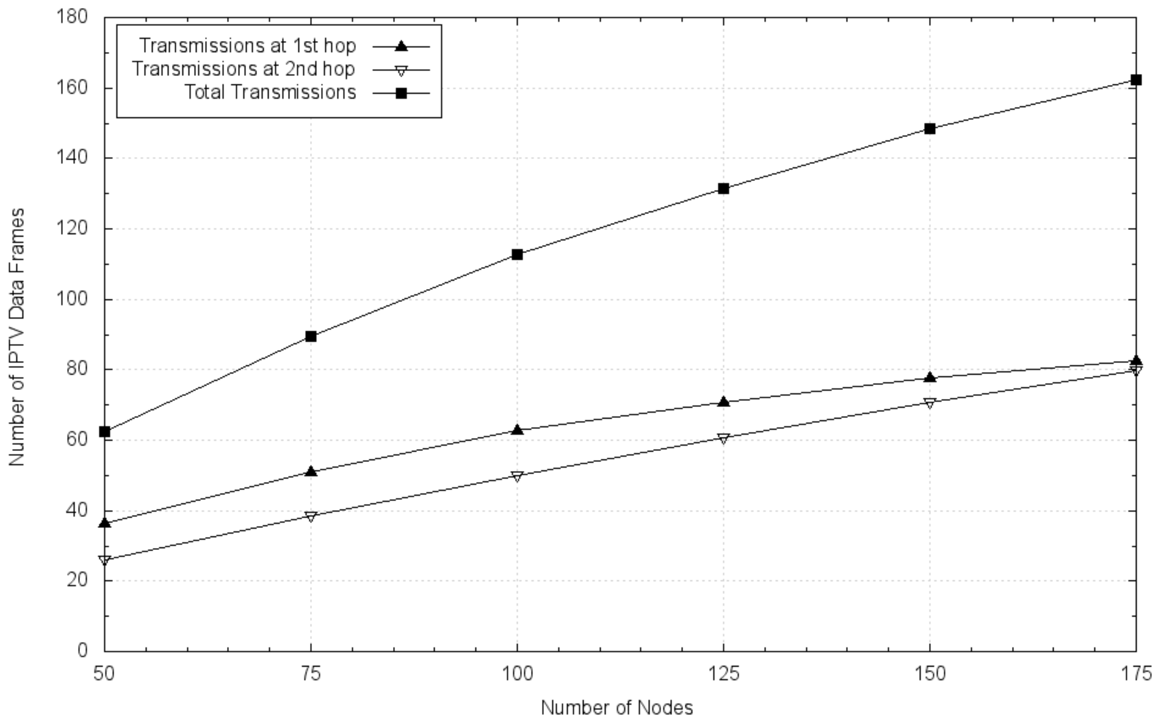

Figure 5.5. Average number of IPTV data frame transmissions in a scheduling round.

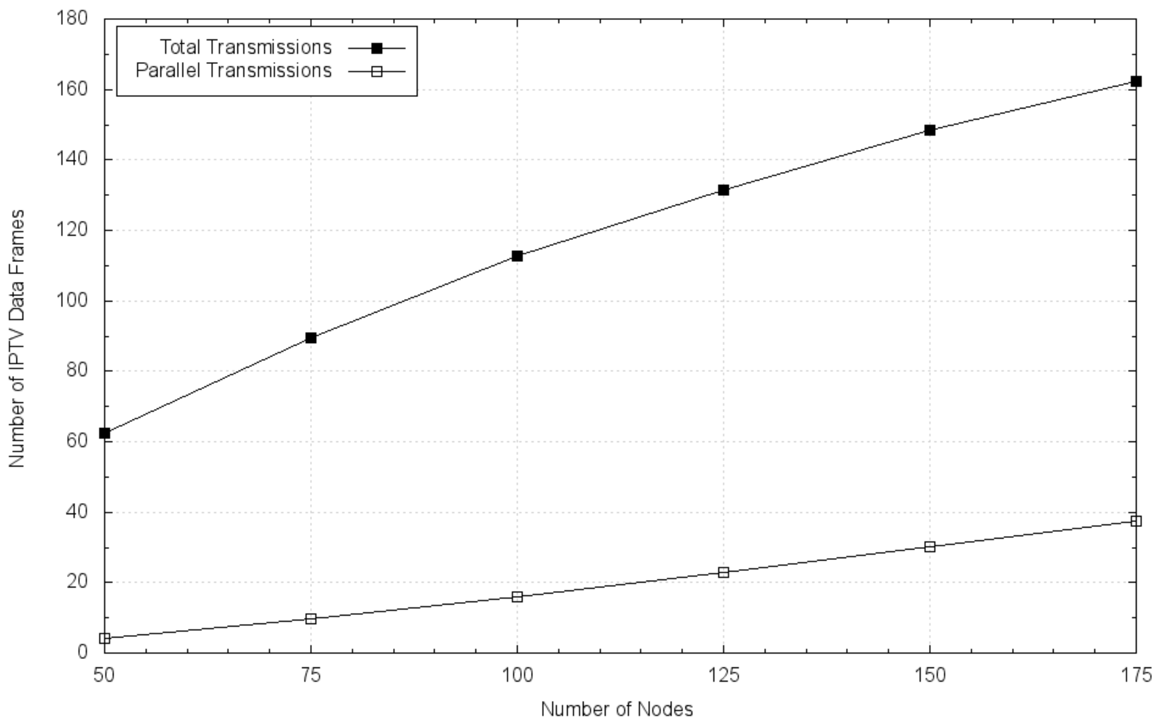

Figure 5.6. Average number of parallel IPTV data frame transmissions in a scheduling round.

Figure 5.6. Considering the total number of transmissions, the total number of IPTV data frame transmissions in a scheduling round has been reduced almost by 20% in the case with 175 nodes.

For the evaluation of the model, the most important criteria for comparison is the delay requirement of the IPTV service. Considering $332 Mbps$ total bandwidth for the highest capacity modulation and coding scheme as shown in Table 2.1 and 6 $Mbps$ data rate requirement for a TV channel as shown in Table 5.5, it is possible to distribute at most 55 distinct TV channels even at single hop operation if no delay is desired. Nevertheless, due to the usage of two-hop Mesh operation, the number of available TV channels is much lower for a delay-free configuration. At this point, allowing delays up to $100ms$ between two consecutive TV channel frames is not expected to deteriorate continuous visual reception by the users according to [51]. Accordingly, simulation runs are stopped in case the average delay between IPTV data frames exceeds $100ms$.

The percentage of IPTV data frames that are delayed more than $100ms$ is shown for the standard WiMAX Mesh, WISDoM, WISDoM-SD, and WISDoM-Hybrid models in Figure 5.7. Allowing at most 1% of the IPTV data frames to exceed the $100ms$ limit (noted as the delay constraint for the rest of this thesis), it is observed that 77 nodes can be served successfully in the standard WiMAX Mesh mode. For the proposed WISDoM model, which only considers relaying over only high capacity links without any parallel transmissions, the capacity of the system is increased to 98 nodes for the same delay constraint. This accounts for approximately 27% increase in node capacity compared to the standard WiMAX Mesh mode. The parallel transmission approach improves the performance of the system even further and the number of nodes that can be served successfully for the given delay constraint is increased to 130 nodes in WISDoM-SD. Overall, the WISDoM-SD model results in nearly 69% increase in node capacity compared to the standard WiMAX Mesh mode and 33% increase in node capacity compared to the WISDoM model. Additionally, it is observed that the WISDoM-Hybrid model has similar results to the WISDoM-SD model. For the hybrid model, the capacity of the system is increased to 128 nodes which accounts for 66% increase compared to the standard WiMAX Mesh mode and 2% decrease compared to the WiMAX-SD model due to the usage of low capacity modulation schemes for a few subscribers who can not use high capacity modulation schemes.

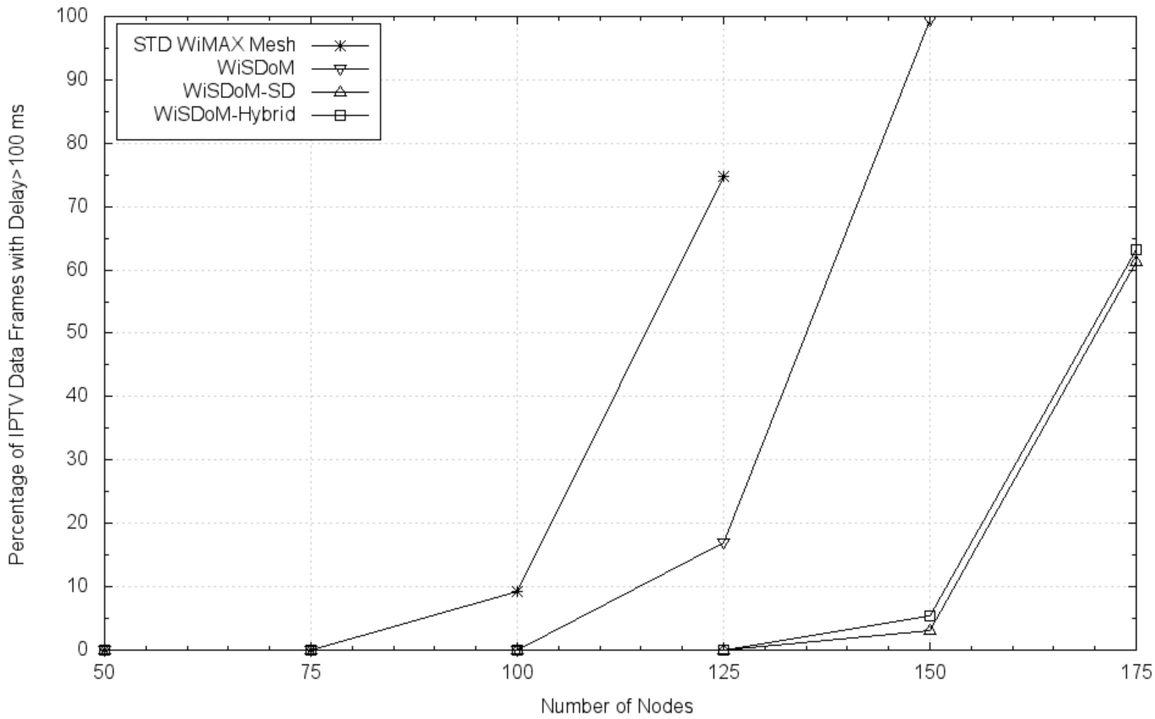

Figure 5.7. Percentage of IPTV data frames delayed above 100 ms.

The average inter-IPTV data frame delay values for the standard WiMAX Mesh, WISDoM, WISDoM-SD, and WISDoM-Hybrid models for the uniform TV channel selection are shown in Figure 5.8. According to this results, the average inter-IPTV data frame delay is observed as 57 ms for the standard Mesh mode when the delay constraint is exceeded. Additionally, it is 71 ms for the WISDoM model and 77 ms for both of the WISDoM-SD and WISDoM-Hybrid models.

As can be observed from the figure, the hybrid model performs between the WISDoM-SD and WISDoM model. However, for the cases with small number of nodes (e.g, 50 nodes) the WISDoM model achieves lower delays than the hybrid model. In the case with 50 nodes, the connectivity is around 90% for the WISDoM model and the hybrid model serves 10% more subscribers compared to the WISDoM model by utilizing more robust (and low capacity) modulation schemes. As a result, slightly higher delays compared to the WiSDoM model are experienced in the hybrid model.

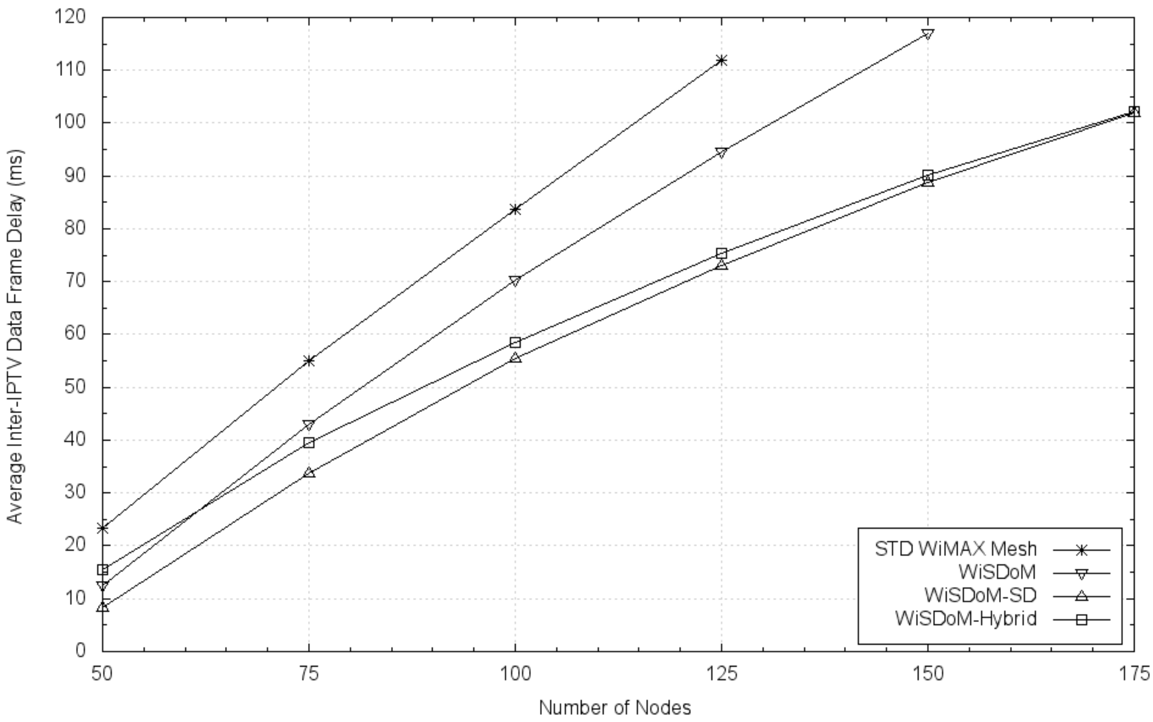

Figure 5.8. Average inter-IPTV data frame delay.

Additionally, when the connectivity in the WISDoM-SD model is close to the WISDoM-Hybrid model as in the case with 175 nodes, both of the models perform very close since there are just a few nodes additionally served with the hybrid model.

The standard deviation in inter-IPTV data frame delay values for simulation runs with different seeds is shown in Figure 5.9. For the models, in which only single modulation scheme is considered (i.e., WISDoM, WISDoM-SD, and WISDoM-Hybrid), the standard deviation in inter-IPTV data frame delays between different simulation runs for given number of nodes is lower than the standard WiMAX Mesh mode. Due to the availability of different modulation schemes in the standard WiMAX Mesh mode, different routing trees combined of paths having different transmission capacities can be constructed depending on the simulation seed. Due to this high standard deviation even at small number of nodes, the delay constraint is exceeded easily in the standard Mesh mode. On the other hand, only highest available modulation and coding scheme (i.e., $64 - QAM$ modulation with coding rate 5/6), which requires smallest transmission slots, is considered for other models (i.e., WISDoM, WISDoM-SD, and WISDoM-

Hybrid). Therefore, there is significantly less variation in inter-IPTV data frame delays compared to the standard WiMAX Mesh mode. Additionally, it is observed that an increase in the number of nodes deployed in the area result in a noticeable increase in delay variations for the standard WiMAX Mesh mode due to the increase in variety of route combinations with different delay characteristics. On the contrary, an increase in the number of nodes does not cause any significant increase in delay variation for inter-IPTV data frame delays in other models.

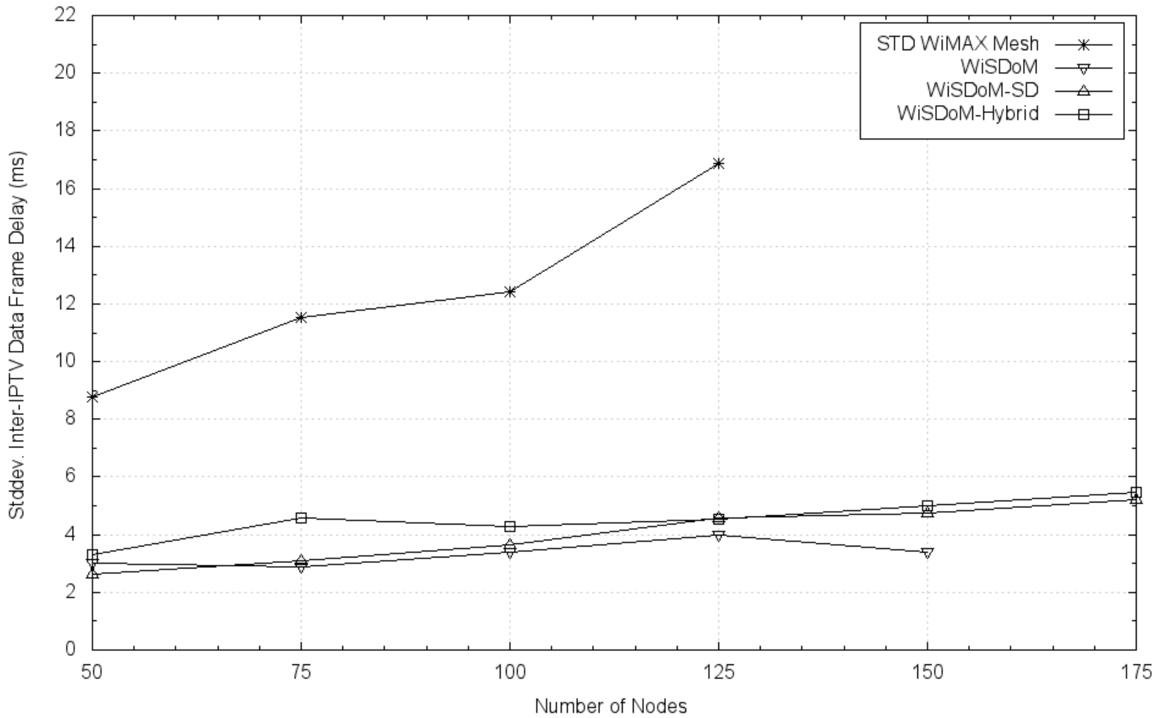

Figure 5.9. Standard deviation of inter-IPTV data frame delay.

5.2.2. Scenario 2: TV Channel Selection with Normal Distribution

Considering the popularity of some TV channels compared to other TV channels in the daily life, a more realistic second scenario in which TV channels are requested with different probabilities is designed. In this scenario, a normal probability distribution function is used for modeling the TV channels request of the users. The TV channels, which are more likely to be requested, are enumerated around TV channel ID 50. Accordingly, the mean of the normal distribution is selected as 50. The standard deviation of the normal distribution is selected as 20. As a result, 40 TV channels with the TV channel IDs between 30 and 70 (i.e., 50 ± 20) are expected to be requested with a probability of 68% and 80 TV channels with channel IDs between 10 and 90 (i.e., 50 ± 40) are expected to be requested with a probability of 95%. For this second scenario, 15 repetitions are performed for the cases with different number of nodes deployed.

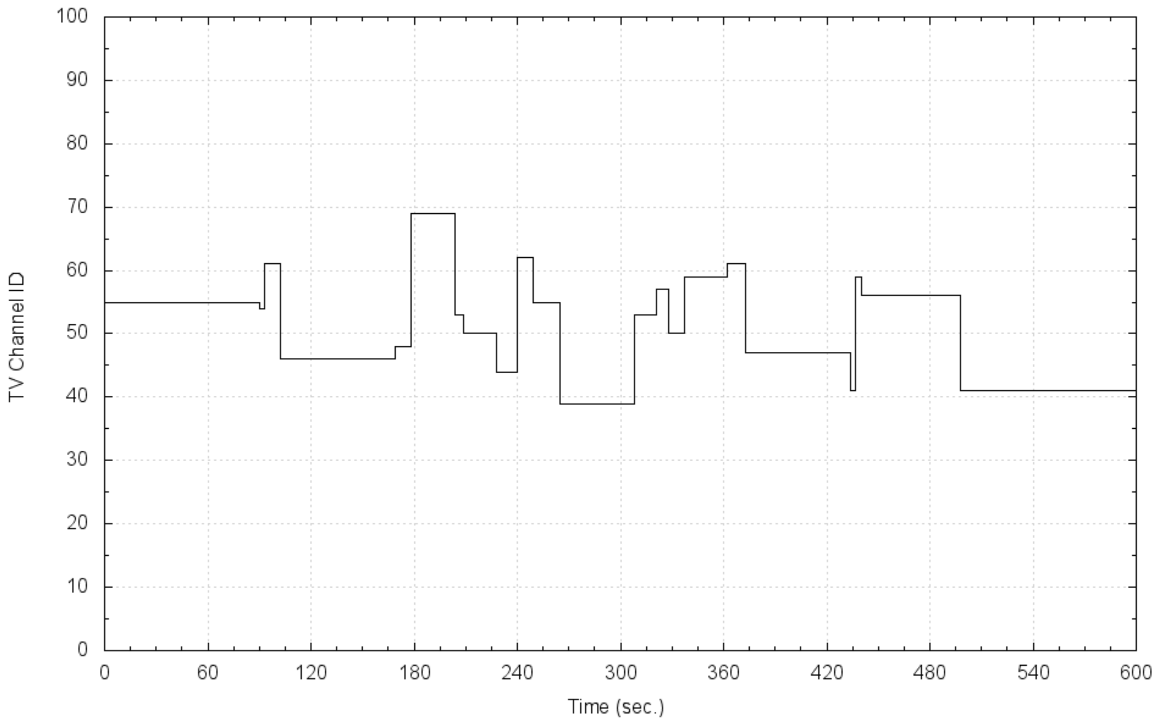

Figure 5.10. Sample TV channel selection histogram of a subscriber station.

The channel request histogram of a sample subscriber station in this second scenario is given in Figure 5.10. As can be observed from the figure, the TV channel requests of a user do not span the whole range of TV channels in this scenario. Instead, the user selects the TV channels mostly around channel ID 50 as expected due to normal probability distribution function.

Different from the uniform TV channel selection case, the users are more likely to select same TV channels in this scenario since normal distribution is used for selection of the TV channels. The average number of distinct channels requested by all users in the network for cases with different numbers of users is shown in Figure 5.11. According to the figure, the number of channels requested is bound around 50 TV channels. This is considerably lower than the result (i.e., 80 TV channels) in the previous scenario with uniform TV channel selection.

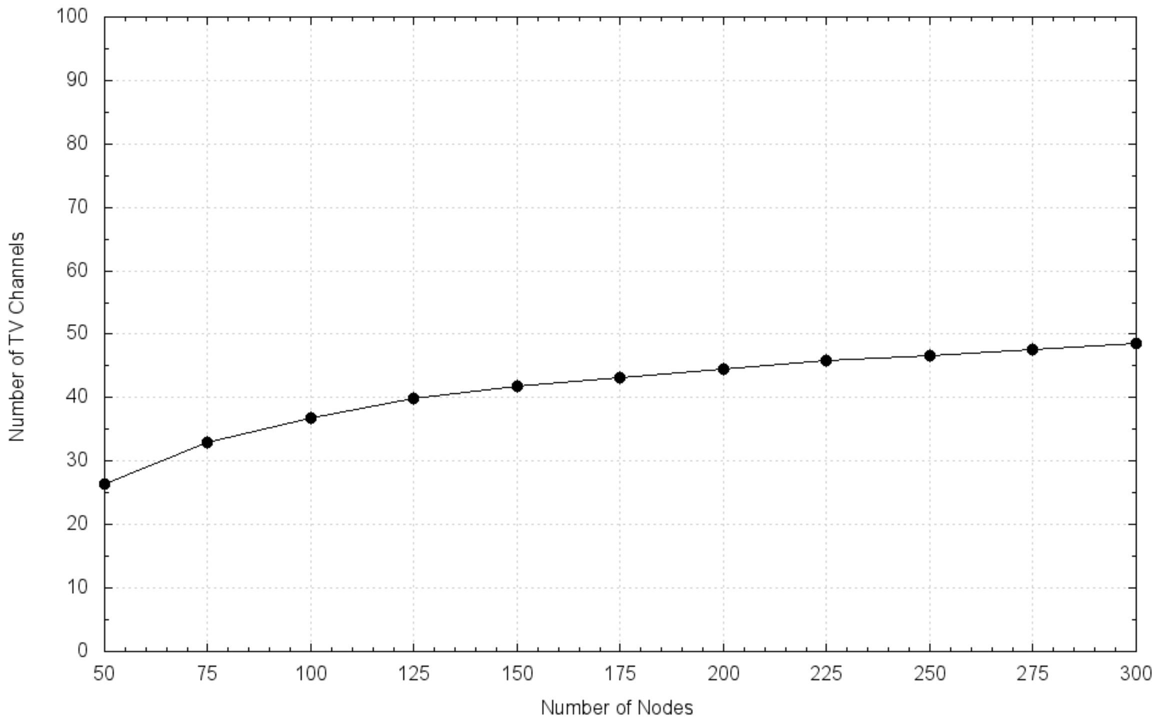

Figure 5.11. Average number of TV channels requested.

Figure 5.12 shows the average number of IPTV data frame transmissions in a scheduling round. As a result of the normal distribution for the selection of the TV channels, the number of transmissions required to distribute all the requested TV channels in the first hop increases gradually as the number of nodes increases. Overall, these first hop transmissions constitute a smaller portion of the total transmissions compared to the number of transmissions required for the second hop, and the main load on system is incurred by relaying (second hop) transmissions.

At this point, the significance of making parallel transmissions to reduce the bandwidth requirements becomes more noticeable. The number of parallel transmissions and the total number of transmissions made are shown in Figure 5.13. Overall, the total number of transmissions have almost been reduced by 29% in the case with 300 nodes.

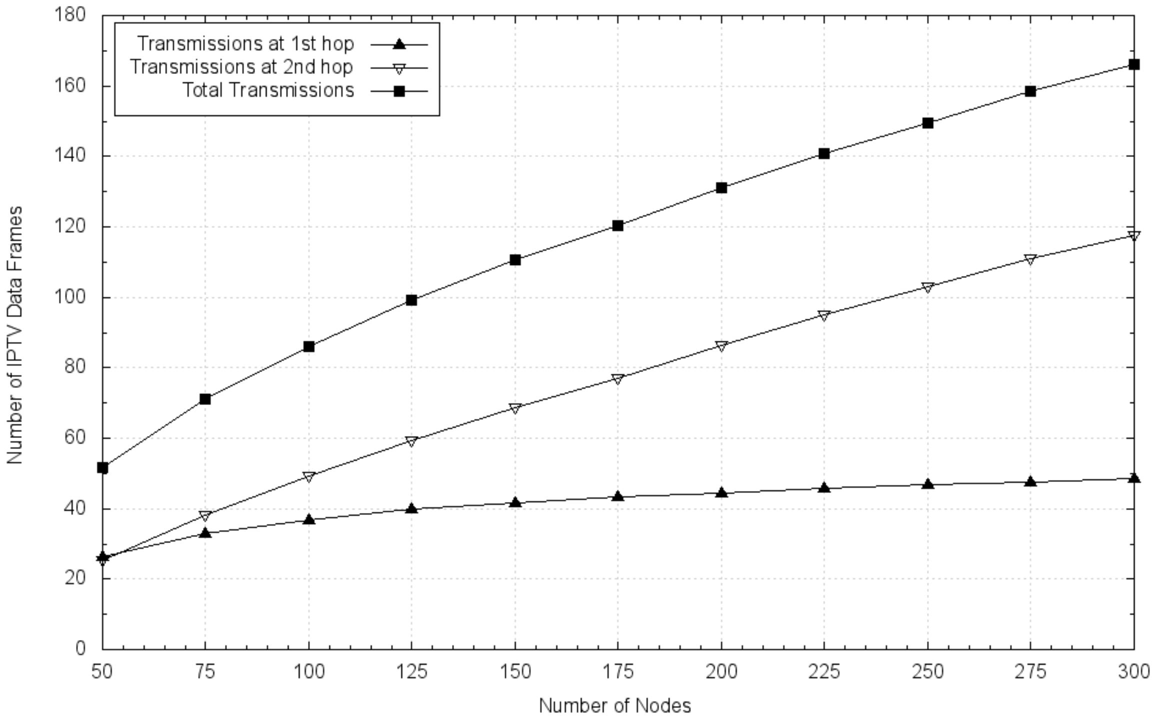

Figure 5.12. Average number of IPTV data frame transmissions in a scheduling round.

The percentage of IPTV data frames that are delayed more than $100ms$ is shown for the WiMAX Mesh, WISDoM, WISDoM-SD, and WISDoM-Hybrid models is shown in Figure 5.14. For the second scenario, the number of nodes that can be served successfully within the delay constraint is observed as 149 nodes in the WISDoM model, which only considers relaying over only high capacity links without any parallel transmissions. Compared to the standard WiMAX Mesh mode in which at most 102 nodes can be served within the given delay constraint, the increase in capacity of the system is around 46%. The parallel transmission approach plays a more significant role in the improvement of the performance of the WISDoM model and the capacity is increased to 228 nodes for the given delay constraint in the WISDoM-SD model accounting for an increase of 124% in node capacity compared to the WiMAX Mesh mode and 53% increase in node capacity compared to the WISDoM model. Additionally, it is observed that the WISDoM-Hybrid model has similar results to the WISDoM-SD model. At most 225 nodes can be served with the WISDoM-Hybrid model which accounts for 121% increase compared to the WiMAX Mesh mode and 1% decrease compared to the

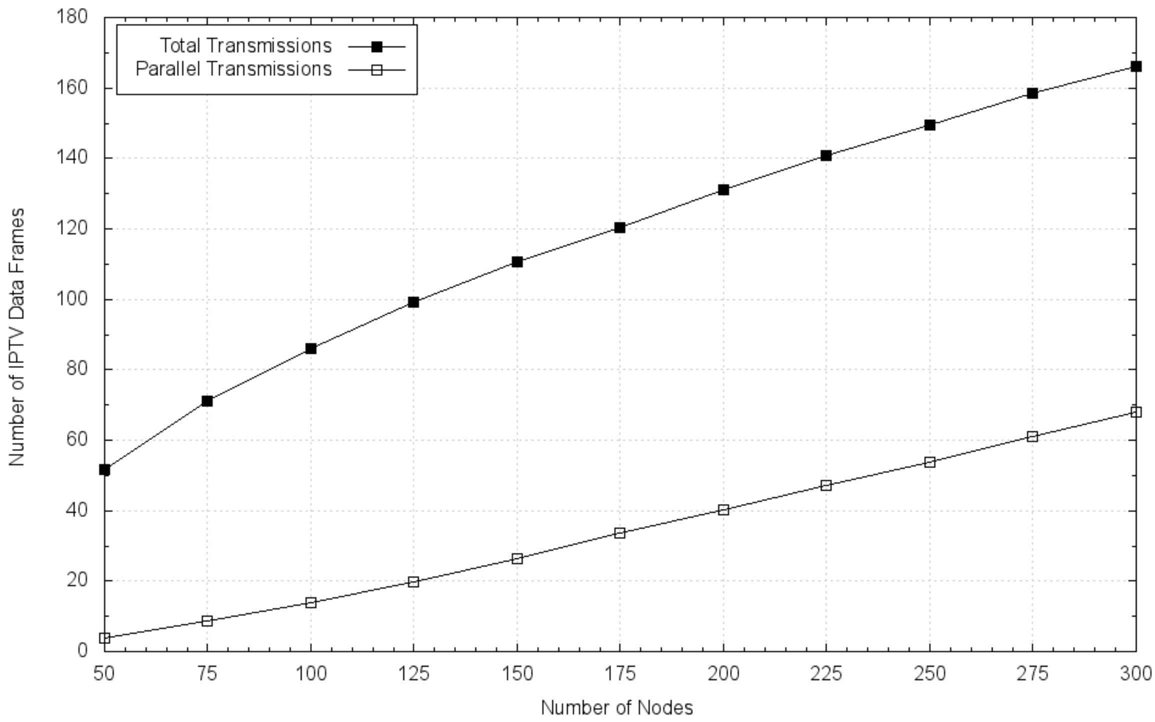

Figure 5.13. Average number of parallel IPTV data frame transmissions in a scheduling round.

WISDoM-SD model.

The average inter-IPTV data frame delay values for the standard WiMAX Mesh, WISDoM, WISDoM-SD, and WISDoM-Hybrid models for the second scenario are shown in Figure 5.15. According to these results, the average inter-IPTV data frame delay is observed as 63 ms for the standard WiMAX Mesh mode when the delay constraint is exceeded. It is 78 ms for the WISDoM model and 83 ms for the WISDoM-SD and WISDoM-Hybrid models.

Similar to the first scenario, the hybrid model performs between the WISDoM-SD and WISDoM model in the second scenario. As the connectivity in the WISDoM-SD model gets closer to the WISDoM-Hybrid model for cases with 175 and higher nodes, both models perform similarly since there are just a few nodes additionally served by the hybrid model. However, for the cases with small number of nodes (e.g, 50 nodes) slightly higher delay values compared to the WISDoM model are observed in the hybrid

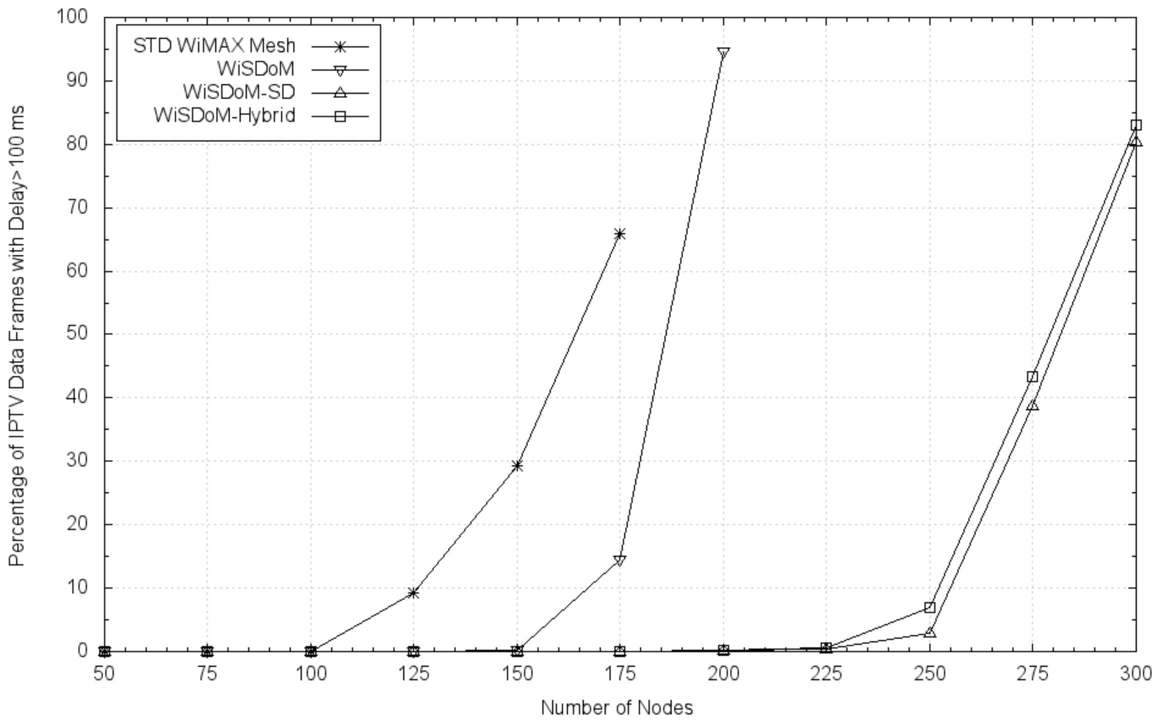

Figure 5.14. Percentage of IPTV data frames delayed above 100 ms.

model similar to the first scenario. In this case, the connectivity is around 90% for the WISDoM model whereas 99% of the nodes are connected in the hybrid model due to utilization of more robust modulation schemes.

The standard deviation in inter-IPTV data frame delay values is shown in Figure 5.16. Similar to the results in the first scenario, standard deviation in inter-frame delays in the standard WiMAX Mesh mode is higher than the models in which only single modulation scheme is considered. Depending on the simulation seed, routing trees with significantly different delay characteristics can be constructed due to the usage of various modulation schemes in the standard WiMAX Mesh mode.

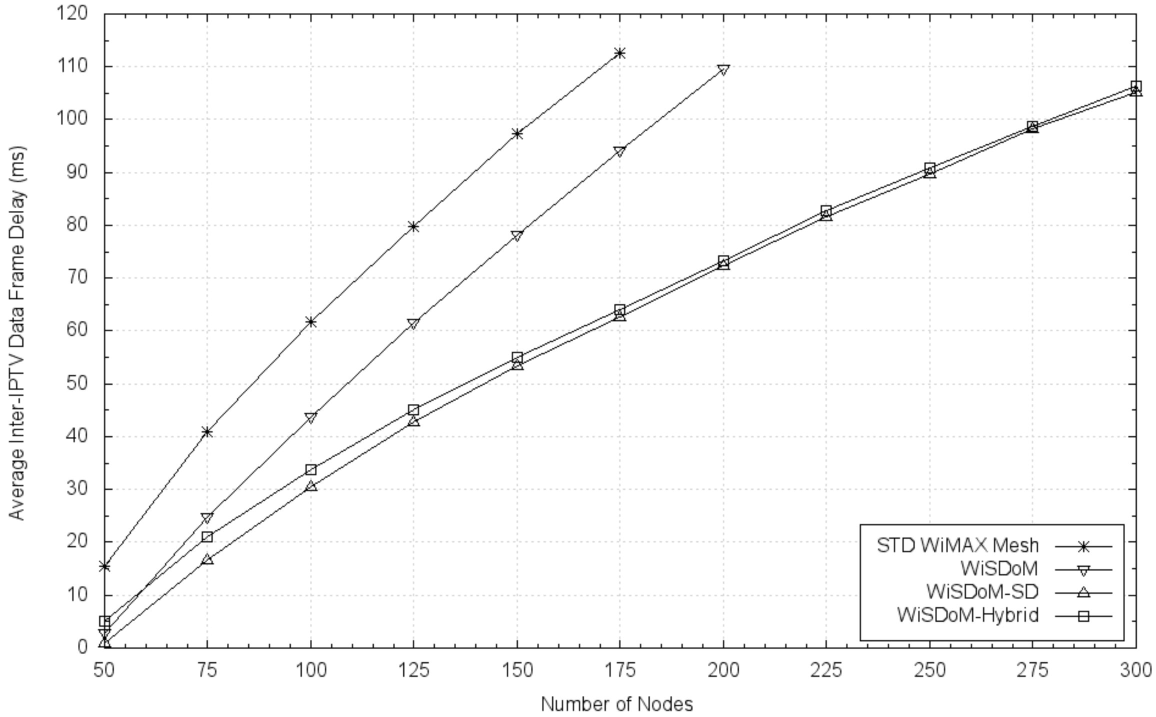

Figure 5.15. Average inter-IPTV data frame delay.

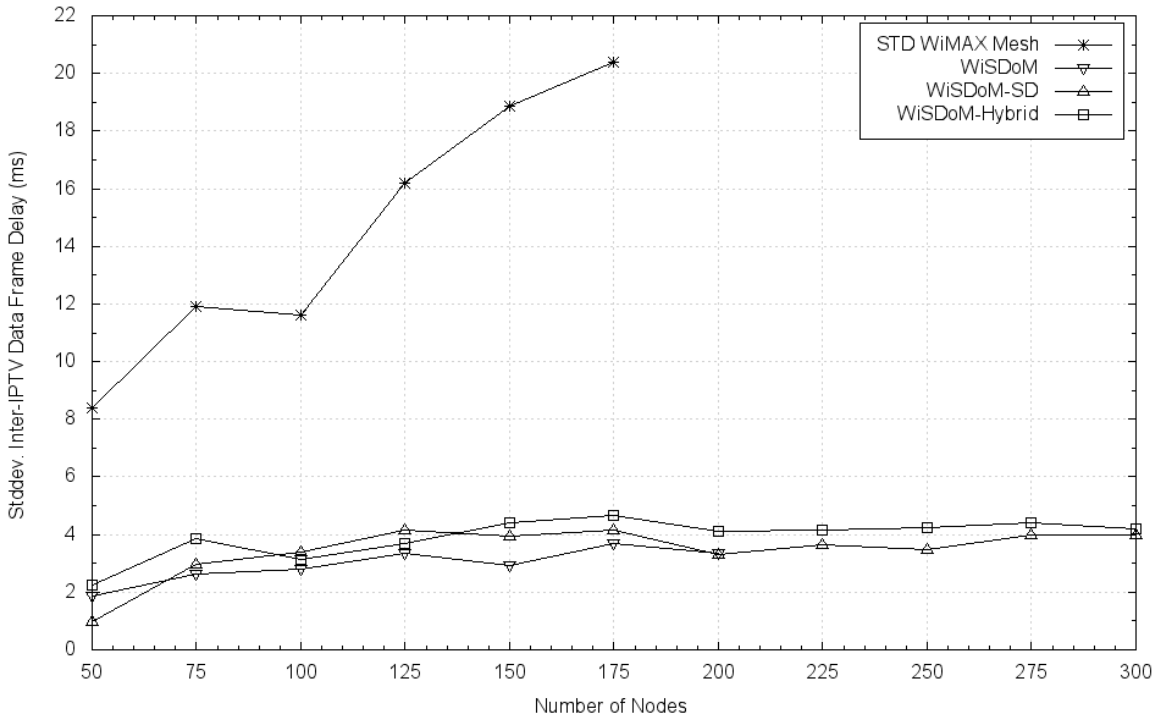

Figure 5.16. Standard deviation of inter-IPTV data frame delay.

6. CONCLUSION

In this paper, an alternative model, named WISDoM-SD, is proposed for the distribution of IPTV based on the WiMAX Mesh mode operation.

In a typical urban/sub-urban environment, many users fail to connect to the BS directly due to varying channel conditions. Although WiMAX Mesh mode solves the connectivity problem, it does not guarantee high bandwidth sufficient for IPTV service. Considering the results in [49], we establish high bandwidth connections to one- and two-hop subscribers.

As a second contribution, we improve the spectral efficiency of the Mesh mode by avoiding the multiple transmissions of the same IPTV data frames to subscribers who experience different channel conditions. We propose that all users who are tuned to the same TV channel are served by a single transmission using the same modulation scheme with relaying where necessary. Moreover, the performance of the standard WiMAX Mesh mode operation is improved by parallel transmissions benefiting from space diversity. For distinct connections, which do not cause interference on each other if transmitted during the same time period, the bandwidth requirement for relaying is minimized by simultaneous transmissions.

Compared to the PMP mode, the number of nodes served is increased from 67% to 90%, even for the case with 50 nodes, which contains less relay opportunities. The connectivity of the nodes is above 99% for the cases with more than 150 nodes. Moreover, the WISDoM-Hybrid model provides connectivity above 99% for all test cases.

For the scenario in which TV channel selection is made via uniform distribution, the number of nodes that can be served successfully for the given delay constraints is increased from 77 nodes in the standard WiMAX Mesh mode to 130 nodes in the WISDoM-SD model. This improvement accounts for approximately 69% increase.

Moreover, considering the more realistic scenario in which TV channel selection is drawn from a normal distribution, the capacity increase is even higher. While the delay bounds are reached for 102 nodes in the WiMAX Mesh mode, the WISDoM-SD model reaches the bounds at 228 nodes, and thereby the user capacity is increased by 124%.

Further improvements on this model can be obtained by examining the tradeoff between more robust modulation schemes and capacity gain. Additionally, utilizing an adaptive burst profile selection scheme can be considered.

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