ENHANCEMENT OF DATA TRANSMISSION FOR MOBILE MULTI HOP RELAY WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS NETWORK

FATH ELRAHMAN ISMAEL KHALIFA AHMED

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To my family

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ABSTRACT

Mobile Multi-hop Relay (MMR) Worldwide Interoperability for Microwave Access (WiMAX) uses Non-Transparent Relay Station (NT-RS) to extend the Base Station (BS) coverage and improve the channel quality and throughput of the network. Nevertheless, the use of NT-RS in MMR WiMAX network increases the delay of relaying packets across multiple hops. Transmission Control Protocol (TCP) and Automatic Repeat reQuest (ARQ) are used to achieve the data transmission reliability in the wireless systems. However, the setting of ARQ parameters are optimised for single hop network and it does not consider the Quality of Service (QoS) limits required of WiMAX networks. In addition, the TCP is adapted to deal with the congestion in the wired network without considering the QoS requirements. In order to enhance the performance of data transmission over MMR WiMAX networks, resource management, transmission control and error control mechanisms should be optimised for MMR WiMAX network. Therefore, this research proposes resource management schemes to decrease the delay of relaying the packets across multiple hops scenario. Transmission control mechanism is then proposed to optimise the transmission control for MMR WiMAX network. Lastly, ARQ parameters are optimised to enhance the link utilisation in order to achieve the QoS rates required. The proposed algorithms performances are evaluated through simulation work. The proposed resource management schemes reduce the delay of relaying packets across multiple hops by 33% and 40% for the second and third hops respectively. Therefore, the link layer throughput is enhanced by 35% and 53% and TCP throughput by 30% and 40% for the second and third hops correspondingly. The proposed transmission control scheme reduces the timeout occurrences which increase the resource utilisation up to 90% and hence the TCP throughput is enhanced by 26% to 75% for different hops. In conclusion, the optimised ARQ parameters for MMR WiMAX network reduce the TCP packet loss by 8%, 44% and 64% for the first, second and third hops. Hence, the link layer and TCP performances are improved by 10% to 140% for diverse scenarios.

ABSTRAK

Kebolehkendalian antara seluruh dunia bagi Akses Gelombang Mikro (WiMAX) iaitu Rangkaian Geganti Berbilang-Lompatan mudah alih (MMR) menggunakan Stesen Geganti Tidak-Telus (NT-RS) untuk melanjutkan Stesen Tapak (BS) liputan dan meningkatkan kualiti saluran dan keluaran rangkaian. Walau bagaimanapun, penggunaan NT-RS dalam rangkaian WiMAX MMR meningkatkan kelewatan paket menghantar ke seluruh berbilang lompatan. Protokol Kawalan Transmisi (TCP) dan permintaan Ulang Automatik (ARQ) digunakan untuk mencapai kebolehpercayaan penghantaran data dalam sistem tanpa wayar. Walau bagaimanapun, ketetapan parameter ARQ di optimumkan bagi rangkaian lompatan tunggal, dan ia tidak mempertimbangkan Kualiti Perkhidmatan (QoS) had yang diperlukan dalam rangkaian WiMAX. Disamping itu, TCP disesuaikan untuk berhadapan dengan kesesakan dalam rangkaian berwayar dan ia tidak mempertimbangkan keperluan QoS WiMAX. Dalam usaha untuk meningkatkan prestasi penghantaran data melalui rangkaian WiMAX MMR, pengurusan sumber, kawalan transmisi dan mekanisme kawalan kesilapan harus dioptimumkan bagi rangkaian WiMAX MMR. Oleh itu, kajian penyelidikan ini mencadangkan skim pengurusan sumber untuk mengurangkan kelewatan paket penyampai melalui senario hop berbilang. Seterusnya, kawalan mekanisme penghantaran adalah dicadangkan untuk mengoptimumkan kawalan penghantaran bagi rangkaian WiMAX MMR. Akhir sekali, ARQ parameter yang optimum untuk meningkatkan penggunaan pautan dalam usaha mencapai kadar QoS yang dikehendaki. Pencapaian, algoritma yang dicadangkan dinilai melalui kerja simulasi. Skim cadangan pengurusan sumber mengurangkan kelewatan paket penyampai melalui hop pelbagai sebanyak 33% dan 40% untuk hop kedua dan ketiga masing-masing. Oleh itu, kendalian pautan lapisan dipertingkatkan oleh 35% dan 53% dan keluaran TCP sebanyak 30% dan 40% untuk hop kedua dan ketiga sepadan. Skim kawalan penghantaran yang dicadangkan mengurangkan kejadian timeout yang meningkatkan penggunaan sumber sehingga 90% dan oleh itu kendalian TCP dipertingkatkan sebanyak 26% kepada 75% untuk hop yang berbeza. Kesimpulannya, parameter ARQ dioptimumkan untuk MMR WiMAX rangkaian mengurangkan kerugian paket TCP sebanyak 8%, 44% dan 64% untuk hop pertama, kedua dan ketiga. Oleh itu, lapisan pautan dan prestasi TCP meningkat sebanyak 10% kepada 140% untuk senario pelbagai.

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LIST OF ABBREVIATIONS

ACK	-	positive Acknowledgement
AGO	-	Accumulated Generation Operation
AIRMAIL	-	Asymmetric Reliable Mobile Access In Link Layer
AMC	-	Adaptive Modulation and Coding
ARQ	-	Automatic Repeat reQuest
ATM	-	Asynchronous Transfer Mode
BE	-	Best Effort
BER	-	Bit Error Rate
BS	-	Base Station
BW	-	Bandwidth
CAC	-	Call Admission Control
CC	-	Convolution Coding
CDMA	-	Code Division Multiple Access
CID	-	Connection Identifier
CRC	-	Cyclic Redundancy Check
CS	-	Convergence Sub-layer
CPS	-	Common Part Sub-layer
CRC	-	Cyclic Redundancy Check
CWND	-	Congestion Window
$CWND_{max}$	-	Maximum Congestion Window
DAA	-	Delayed Duplicate Acknowledgement
DAWL	-	Delayed ACK on wireless Link
DC	-	Direct Current
DL	-	Downlink
DL-AZ	-	Downlink Access Zone
DL-MAP	-	Slot allocation for downlink transmission
DL-RZ	-	Downlink Relay Zone

DSL	-	Digital Subscriber Line
EBSN	-	Explicit Bad State Notification
ELN	-	Explicit Loss Notification
E-mail	-	Electronic Mail
ERR	-	Extra Resource Reservation
ertPS	-	Extended Real Time Polling Service
FCH	-	Frame Control Header
FEC	-	Forward Error Correction
FFT	-	Fast Fourier Transform
FH	-	Fixed Host
FTP	-	File Transfer Protocol
FUSC	-	Fully Used Sub-Carrier
GHz	-	Giga Hertz
GMH	-	Global Management Header
HARQ	-	Hybrid Automatic Repeat reQuest
I-AGO	-	Inverse Accumulated Generation Operation
ID TLV	-	Type, Length and value of the Identifier
IE	-	Information Element
IEEE	-	Institute of Electrical and Electronics Engineering
I-TCP	-	Indirect Transmission Control Protocol
LLE-TCP	-	Link Layer ARQ Exploitation TCP
LOS	-	Line Of Sight
MAC	-	Medium Access Control
METP	-	Mobile End Tranport Protocol
MHz	-	Mega Hertz
MMR	-	Mobile Multi-hop Relay
MPDU	-	Multiple Packet Data Unit
MSDU	-	Multiple Service Data Unit
NACK	-	Negative Acknowledgement
NLOS	-	Non Line Of Sight
nrtPS	-	Non Real Time Polling Service
NT-RS	-	Non Transparent Relay Station
OFDM	-	Orthogonal Frequency Division Multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access

ORS	-	OFDMA Relay Scheduler
OSI	-	Open System Interconnection
PDU	-	Packet Data Unit
PER	-	Packet Error Rate
PKM	-	Privacy Key Management
PMP	-	Point to Multi Point
PSK	-	Phase Shift Keying
PHY	-	Physical Layer
PUSC	-	Partially Used Sub-Carrier
QAM	-	Quadrature Amplitude Modulation
QoS	-	Quality of Service
QPSK	-	Quadrature Phase Shift Keying
RF	-	Radio Frequency
R-FCH	-	Relay Frame Control Header
R-MAC	-	Relay Medium Access Control
R-MAP	-	Slot allocation for Relay Station transmission
RNG-REQ	-	Range Request message
RNG-RSP	-	Range Response message
RS	-	Relay Station
RS-ARQ	-	Relay Station support Automatic Repeat reQuest
RS-ID	-	Relay Station Identifier
RSSI	-	Received Signal Strength Indicator
RTG	-	Receive to Transmit Gap
RTO	-	Retransmission Time Out
rtPS	-	Real Time Polling Service
RTT	-	Round Trip Time
SACK	-	Selective Acknowledgement
SC	-	Single Carrier
SDU	-	Service Data Unit
SFID	-	Service Flow Identifier
SINR	-	Signal to Interference and Noise Ratio
SNR	-	Signal to Noise Ratio
SQSA	-	Scalable QoS Scheduling Architecture
SRTT	-	Smoothed Round Trip Time

SS	-	Subscriber Station
ssthresh	-	Slow Start Threshold
T-CID	-	Tunnel Connection Identifier
TCP	-	Transmission Control Protocol
TCP/IP	-	Transmission Control Protocol/Internet Protocol
TDMA	-	Time Division Multiple Access
TDD	-	Time Division Duplex
TLV	-	Type, Length and value of any parameter
TRG	-	Transmit to Receive Gap
T-RS	-	Transparent Relay Station
UGS	-	Unsolicited Grant Service
UL	-	Uplink
UL-AZ	-	Uplink Access Zone
UL-MAP	-	Slot allocation for uplink transmission
UL-RZ	-	Uplink Relay Zone
UWB	-	Ultra Wide Band
VoIP	-	Voice of Internet Protocol
VRTT	-	Variance of Round Trip Time
Wi-Fi	-	Wireless Fidelity
WiMAX	-	World wide Interoperability of Microwave Access
WLAN	-	Wireless Local Area Network
WMAN	-	Wireless Metropolitan Area Network
WPAN	-	Wireless Personal Area Network
WTCP	-	Wireless Transmission Control Protocol
WWAN	-	Wireless Wide Area Network

LIST OF NOTATIONS

Notation	**-**	**Explanation**
$ARQ^{opt}_{block\_life}$	-	Optimum ARQ block lifetime
$ARQ^{opt}_{p\_size}$	-	Optimum ARQ packet size
$ARQ^{opt}_{retry\_time}$	-	Optimum ARQ retry timeout
$ARQ^{Q\_hops}_{retry\_time}$	-	Optimum ARQ retry timeout for Q hops
$ARQ^{opt}_{w\_size}$	-	Optimum ARQ window size
BER_i	-	Bit error rate at instance i
CAC^{opt}	-	Optimum Call Admission Control
$CWND^{opt}_{\max}$	-	Optimum maximum congestion window
DF_Q	-	Delay factor of hop number Q
$(DL_{Ratio})_{MMR-BS}$	-	Downlink Ratio of MMR-BS OFDMA frame
$(DL\_AZ)_{MMR-BS}$	-	Downlink access zone of the MMR-BS
$(DL\_AZ)_{NT-RS^n_1}$	-	Downlink access zone of the NT-RS number n in the 1st tier
$(DL\_AZ)_{NT-RS^n_2}$	-	Downlink access zone of the NT-RS number n in the 2nd tier
$(DL\_RZ)_{MMR-BS}$	-	Downlink relay zone of the MMR-BS
$(DL\_RZ)_{NT-RS^n_1}$	-	Downlink relay zone of the NT-RS number n in the 1st tier
$(DL\_RZ)_{NT-RS^n_2}$	-	Downlink relay zone of the NT-RS number n in the 2nd tier
D_{wired}	-	The delay of the wired part of the network

FPS	-	Frame per second
$Link_{per}$	-	Link layer performance
$MAX_{ARQ\_packet\_size}$	-	Maximum ARQ packet size
Mod^{opt}	-	Optimum modulation scheme
$N_{avail,slots}^{all\_links}$	-	available slots in the all the links between the MMR-BS and access link where the SS located
$N_{total,SSs}^{all\_NT-RS}$	-	Total number of SSs served by the all NT-RS
$N_{slots}^{All\_packets\_q_{NT-RS_i}}$	-	Number of slots required to forward the packets stored in a queue of $NT\text{-}RS_i$
$N_{excess,slots}^{all\_SSs}$	-	Excess slots allocated to other SSs in the access link where the new coming SS located
$N_{slots}^{available}$		Number of available slots in the access zone of the RS
$N_{channels}^{(DL)_{MMR-BS}}$	-	Number of logical channels in the downlink of the MMR-BS
$N_{slots}^{(DL)_{MMR-BS}}$	-	Number of slots in the downlink of the MMR-BS
$N_{symb}^{(DL)_{MMR-BS}}$	-	Number of OFDMA symbols in the downlink sub-frame of the MMR-BS
$N_{remain,slots}^{(DL\_AZ)_{MMR-BS}}$	-	Remain of SSs in the downlink access zone of the MMR-BS
$N_{slots}^{(DL\_AZ)_{MMR-BS}}$	-	Number of slots in the downlink access zone of the MMR-BS
$N_{SSs}^{(DL\_AZ)_{MMR-BS}}$	-	Number of SSs in the downlink access zone of the MMR-BS
$N_{unserved,SSs}^{(DL\_AZ)_{MMR-BS}}$	-	Number of un-served SSs in the downlink access zone of the MMR-BS
$N_{slots}^{(DL\_AZ)_{NT-RS_1^n}}$	-	Number of slots in the downlink access zone of the 1st tier NT-RS
$N_{slots}^{(DL\_AZ)_{NT-RS_2^n}}$	-	Number of slots in the downlink access zone of the 2nd tier NT-RS
$N_{slots}^{(DL\_RZ)_{MMR-BS}}$	-	Number of slots in the downlink relay zone of the MMR-BS

$N_{slots}^{(DL\_RZ)_{NT-RS_1^n}}$	-	Number of slots in the downlink relay zone of the 1st tier NT-RS
$N_{slots}^{(DL\_RZ)_{NT-RS_2^n}}$	-	Number of slots in the downlink relay zone of the 2nd tier NT-RS
$N_{Cont,subcarr}^{frame}$	-	Number of frequency sub-carriers per frame used to send control messages
$N_{Data,subcarr}^{frame}$	-	Number of frequency sub-carriers per frame used to send data
$N_{subcarr}^{frame}$	-	Number of frequency sub-carriers per frame
N_{symb}^{frame}	-	Number of OFDMA symbols per frame
$N_{\max\_rate,slots}^{new\_SS}$	-	Required slots to satisfy the maximum data rate of the new coming SS
$N_{\min\_rate,slots}^{new\_SS}$	-	Required slots to satisfy the minimum data rate of the new coming SS
$N_{SSs}^{NT-RS_i^n}$	-	Number of SSs served by the NT-RS number n in the ith tier
$N_{slots}^{NT-RS_i\_fair\_usage}$	-	Number of slots that satisfy fair usage of the available resources of the $NT\text{-}RS_i$
$N_{slots}^{NT-RS_i\_greypred}$	-	Number of slots calculated from the bandwidth demand estimated by the grey prediction algorithm for the $NT\text{-}RS_i$
$N_{slots}^{required}$	-	Number of slots required to send the data stored in RS' queue
$N_{requested,slots}^{SS}$	-	Number of slots requested by the SS to send its uplink data
$N_{required,slots}^{SS}$	-	Required slots to send the SS data
$N_{slots}^{SS\_fair\_usage}$	-	Number of slots that can satisfy fair usage of the available resources among SSs
$N_{channels}^{(UL)_{MMR-BS}}$	-	Number of logical channels in the uplink of the MMR-BS
$N_{slots}^{(UL)_{MMR-BS}}$	-	Number of slots in the uplink of the MMR-BS
$N_{symb}^{(UL)_{MMR-BS}}$	-	Number of OFDMA symbols in the uplink sub-frame of the MMR-BS
$N_{remain,slots}^{(UL\_AZ)_{MMR-BS}}$	-	Remain of SSs in the uplink access zone of the MMR-BS

$N_{slots}^{(UL\_AZ)_{MMR-BS}}$	-	Number of slots in the uplink access zone of the MMR-BS
$N_{SSs}^{(UL\_AZ)_{MMR-BS}}$	-	Number of SSs in the uplink access zone of the MMR-BS
$N_{unserved\_SSs}^{(UL\_AZ)_{MMR-BS}}$	-	Number of un-served SSs in the uplink access zone of the MMR-BS
$N_{slots}^{(UL\_AZ)_{NT-RS_1^n}}$	-	Number of slots in the uplink access zone of the 1st tier NT-RS
$N_{slots}^{(UL\_AZ)_{NT-RS_2^n}}$	-	Number of slots in the uplink access zone of the 2nd tier NT-RS
$N_{slots}^{(UL\_RZ)_{MMR-BS}}$	-	Number of slots in the uplink relay zone of the MMR-BS
$N_{slots}^{(UL\_RZ)_{NT-RS_1^n}}$	-	Number of slots in the uplink relay zone of the 1st tier NT-RS
$N_{slots}^{(UL\_RZ)_{NT-RS_2^n}}$	-	Number of slots in the uplink relay zone of the 2nd tier NT-RS
$N_{RTO\_expired}$	-	Number of RTO timer expiration
N_{SS}	-	Number of subscriber stations
$P_{TCP\_loss}^{1}$	-	The probability of the TCP packet loss sent for one hop
$P_{TCP\_loss}^{Q}$	-	The probability of the TCP packet loss sent across Q hop
$P_{TCP\_loss\_N}$	-	TCP packet loss estimation at iteration N
$Packet_{size}$	-	Link layer packet size in bytes
$Packet_{size\_optimum}$	-	Optimum link layer packet size in bytes
$PER^{2^{nd}\&3^{rd}}$	-	Packet error rate for the second and third hops
PER_i	-	Packet error rate at instance i
PL_Q	-	Packet loss factor of hop number Q
$R_{allocated}^{SS}$	-	Allocated resources for a given SS
$R_{available}^{SS}$	-	Available resources for a given SS
R_{link}^{SS}	-	Link layer rate of a given SS
$R_{(DL\_AZ)_{MMR-BS}}$	-	Sending rate in bits per frame for the DL_AZ of the MMR-BS

$R_{(DL\_RZ)_{MMR-BS}}$	-	Sending rate in bits per frame for the DL_RZ of the MMR-BS
$R_{\max\_sustained}$	-	Required resources to satisfy the maximum sustained rate
$R_{\min\_reserved}$	-	Required resources to satisfy the minimum reserved rate
$R_{(UL\_AZ)_{MMR-BS}}$	-	Sending rate in bits per frame for the UL_AZ of the MMR-BS
$R_{(UL\_RZ)_{MMR-BS}}$	-	Sending rate in bits per frame for the UL_RZ of the MMR-BS
$R_{utilized}$	-	Utilization of the allocated resources
$\mathrm{Re}_{overlap}$	-	Retransmission overlapping from different layers
Re_{un_necess}	-	Un-necessary retransmission
$RTT_{avg,k}$	-	Average round trip time at instance k
$RTO^{opt}_{smoothed}$	-	Optimum smoothed retransmission timeout
$Schedule^{opt}$	-	Optimum scheduling
SNR_i	-	Signal to noise ratio at instance i
$SRTT(k)$	-	Smoothed round trip time at instance K
$ssthresh^{opt}$	-	Optimized slow start threshold value
$ssthresh_{norm}$	-	Normalized slow start threshold value
T_{Eff}	-	Transmission Efficiency
T_{Eff_N}	-	Transmission Efficiency at iteration N
$T_{Link\_ACK,receive}$	-	The time when all link layer ACKs received
t_{proc}	-	Processing time
t_{prop}	-	Propagation time
T_{recov}	-	Error recovery time
$T_{TCP\_ACK,send}$	-	The time when TCP ACK is sent from the MMR-BS
$T_{TCP,receive}$	-	The time when the TCP packet is received at the MMR-BS

$T_{TCP,send}$	-	The time when the TCP packet is sent from the fixed host
TCP_{per}	-	Transmission Control Protocol performance
TCP_{seg_size}	-	TCP segment size in bytes
$(UL_{Ratio})_{MMR-BS}$	-	Uplink Ratio of MMR-BS OFDMA frame
$(UL\_AZ)_{MMR-BS}$	-	Uplink access zone of the MMR-BS
$(UL\_AZ)_{NT-RS_1^n}$	-	Uplink access zone of the NT-RS number n in the 1st tier
$(UL\_AZ)_{NT-RS_2^n}$	-	Uplink access zone of the NT-RS number n in the 2nd tier
$(UL\_RZ)_{MMR-BS}$	-	Uplink relay zone of the MMR-BS
$(UL\_RZ)_{NT-RS_1^n}$	-	Uplink relay zone of the NT-RS number n in the 1st tier
$(UL\_RZ)_{NT-RS_2^n}$	-	Uplink relay zone of the NT-RS number n in the 2nd tier
$VRTT(k)$	-	Variation of round trip time at instance k
τ_{DL_frame}	-	Downlink sub-frame duration
τ_{UL_frame}	-	Uplink Sub-frame duration

LIST OF SYMBOLS

a	-	Development Coefficient of Grey Prediction algorithm
b	-	Input to the Grey Predictor
D	-	Net data packet size in bytes
e	-	Exponential constant
h	-	Packet header size in bytes
i	-	Hop count
m	-	Weight constant
M	-	Modulation index
N	-	Number of fragments of one TCP packet
k	-	Forecasting Step Size of Grey Prediction algorithm
Q	-	Number of hops
R	-	Number of retransmissions
t	-	Time
α	-	Exponential smoothing parameter
β	-	Smoothing parameter
τ	-	OFDMA frame duration
ψ	-	The order of RS where the packet is corrupted
φ	-	Number of sequence values used in Grey Prediction algorithm

LIST OF APPENDICES

CHAPTER 1

INRODUCTION

1.1 Background

The demand for wireless access has increased exponentially. This is due to flexibility, portability and less installation cost features [1-2]. Currently, many wireless data transmission technologies with different capabilities and features are available. The recent developments of wireless access system technologies such as Worldwide Interoperability for Microwave Access (WiMAX) allow them to provide higher data rates. These features make the WiMAX systems as one of the next generation candidates [3]. The wireless technologies are categorized to different network families, based on their coverage ranges. In the next sub-sections, various wireless categories and data network protocols will be discussed.

1.1.1 Wireless Communication Systems

The first category with the shortest range network is a Wireless Personal Area Network (WPAN), which is used to transfer data between devices in very short distances. The range of WPAN network is in order of a few metres, less than 10m in most of the cases. There are many WPAN technologies in use now such as Ultra Wide Band (UWB), Bluetooth and Zigbee [4-7]. Next, is Wireless Local Area

Network (WLAN), which is a data network that covers relatively small area, such as a home, an office or a small campus. The most widely used WLAN technologies is Wireless Fidelity (WiFi) [8]. On the other hand, Wireless Metropolitan Area Network (WMAN) is a data network that may cover up to several kilometres, typically a large campus or a city. Fixed Worldwide Interoperability for Microwave Access (WiMAX), Mobile WiMAX and Mobile Multi-hop Relay (MMR) WiMAX are considered as a WMAN [9]. Lastly, a Wide Area Network (WAN) is a data network covering a wide geographical area, as big as country, continent or globally. WAN is constructed by connecting multiple of WLANs and/or WMANs together, which allows Subscriber Stations (SSs) in one location to communicate with SSs in other locations [10].

This thesis focuses on WiMAX network. It operates in a frequency range from 10 to 66 GHz and supports both Line of Sight (LOS) and Non LOS (NLOS). LOS is required at higher frequencies, however lower frequencies operate in NLOS manner. The network is deployed like single hop cellular systems using Base Stations (BS) to provide service to SSs within a radius of several miles/kilometres. The service coverage distance is up to 30 miles with decreasing performance toward the boundaries. The transmission rate limit depends on the distance from the BS as well as channel quality. WiMAX network is point-to-multipoint (PMP) technology that is used to provide last mile broadband connectivity to end SSs. It is capable of providing higher data rates that is comparable with cable and Digital Subscriber Line (DSL) rates [11]. In addition, the coverage area supported by WiMAX is much larger than WLAN. Furthermore, it is used to connect SSs to a wireless Internet service provider with the flexible mobility and roaming outside their home or business office. Therefore, WiMAX networks can be used to replace the wired broadband connections or extend the services to the rural areas where there is no infrastructure [12-15].

As mentioned before, service quality of single hop WiMAX degrades near the cell boundary due to bad channel state. Therefore, a multi-hop system using Relay Station (RS) to relay data packets between BS and the end SSs is introduced [3, 16]. The introduction of RS enhances the throughput at the cell boundaries as well as extending the coverage to the places where weak signal is received or no coverage. There are two types of the RS; Transparent RS (T-RS) and Non Transparent RS (NT-RS). The network utilizing this multi-hop structure is called Mobile Multi-hop Relay (MMR) WiMAX network. Despite the benefits of using RS in the MMR WiMAX network, resource management schemes should be adapted to incorporate RS operation. This issue arises because in multi-hop system there are more than one intermediate nodes where their transmission should be coordinated to reduce the delay as well as maximizing the resource utilization [17].

1.1.2 Data Network Protocol Model

Network functionalities and services are classified and modelled through the well-known Transmission Control Protocol/Internet Protocol (TCP/IP) network model. It contains 5-layer protocol stack where each layer defines the specifications for a particular network aspect and provides services to the upper layers. Figure 1.1 shows the layered hierarchy of the TCP/IP stack of the source and destination nodes and the intermediate nodes of the WiMAX system. The WiMAX standard specifies only Medium Access Control (MAC) and physical (PHY) layers for combined fixed and mobile operation in licensed frequency bands [18].

The functionalities of the layers in the TCP/IP protocol stack are as follow: The application layer is responsible of session creation between source and destination SSs and defining the SS applications. The transport layer provides a virtual end-to-end channel between sender and receiver. The Network Layer handles the routing of data flow from source to destination through the network. The MAC provides the abstraction of a link and the ability to transmit raw of bits over the channel. MAC layer provides flow control, acknowledgment, error recovery, and transmission scheduling which can be implemented in centralized or distributed manner. The physical layer deals with signal transmission over the channel. The modularity of the network design is achieved by layered protocol that allows layers at the same level to communicate with each other. These protocols allow each layer to be optimized separately. However, in wireless networks there is a need to increase inter-layer communication in order to deal with wireless channel variation and to satisfy the services requirements. Thus the control mechanisms at the application, transport, network, MAC and physical layers need to be jointly designed in order to achieve better performance.

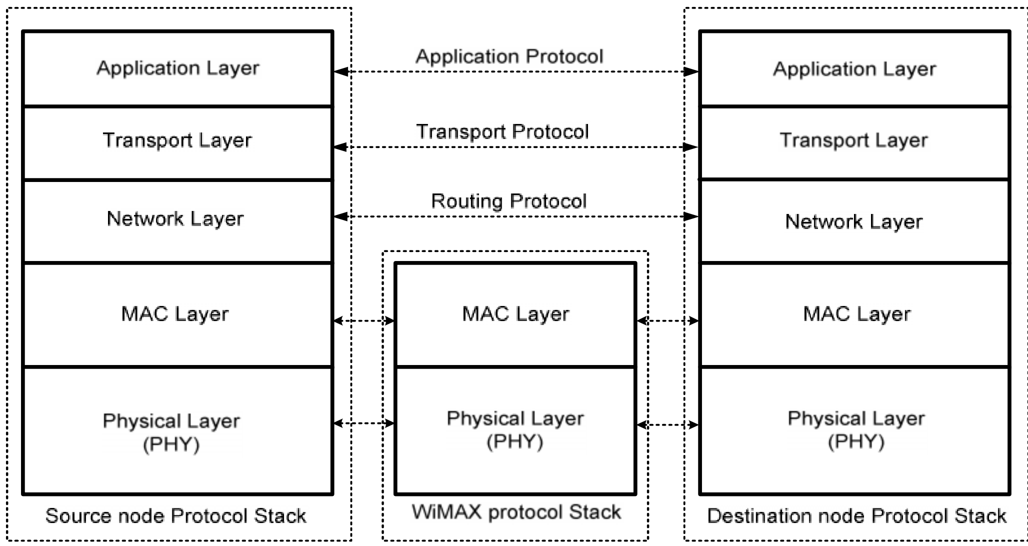

Figure 1.1 TCP/IP protocol stack model

Since, data packets are sent through wireless systems, they may be corrupted due to impairments in the wireless channel. Therefore, reliable transmission techniques are needed to provide the reliability of sending data in wireless networks. This reliability is gained by applying Forward Error Correction (FEC) algorithms that attempt to detect and correct the errors induced to the data [19]. The FEC techniques add redundancy bits to the transmitted data blocks to help the receiver to detect and correct errors. However, FEC is only able to detect and correct small number of errors. In order to enhance FEC capability, more redundancy bits should be added which reduces the transmission efficiency.

Alternatively, Transmission Control Protocol (TCP) which is implemented at transport layer is used to retransmit the corrupted data segment. TCP is the most commonly transport protocol used in the Internet to provide end-to-end connection oriented and reliable services [20]. The file transfer activities which uses TCP composes more than 90% of the Internet traffic [21]. In TCP, after inferring that a packet is lost, it retransmits the packet and re-adjusts the transmission rate to avoid more packets loses. TCP protocol is optimized to be used in wired networks where congestion is the only cause of packet loss. It responds to segment loss by shrinking its transmission window, and this reduces the throughput of TCP traffic [20]. On the other hand, in wireless networks, packet loses are due to errors in link layer and disconnection due to handoff rather than congestion. Normally, more than one techniques can be used together to achieve reliability [22]. This motivates the use of Automatic Repeat reQuest (ARQ) at link layer to enhance link situation [22]. ARQ attempts to hide wireless losses from TCP protocol by solving error problem locally at link layer. However, it introduces variable transmissopn delay which causes frequent TCP timeout and hence degrade performance. For multi-hop system, delay variation is increased which rises the possibility of timeout. In addition, when multi-hop MMR WiMAX network is considered, transmission time delay is varied with hop level and hence various transmission rates are provided to the SSs at the different hops [23]. On the other hand, correct adjustment of ARQ parameters plays an important role in enhancing the performance of wireless communication system. ARQ parameters that are well optimized for single hop systems can give better resource utilization and less error recovery time [24-27]. However, ARQ parameters are not optimized for multi-hop systems and not aware of services requirements [28-30].

1.2 Issues and Challenges

To satisfy SSs requirements, MMR WiMAX system must be able to provide equal service quality to the SSs at different hops and satisfies Quality of Service (QoS) services requirements. Yet, for MMR WiMAX to be successful, there are some issues and challenges that have to be considered. Some of the interesting research questions are stated in the following points.

- How to develop a resource management scheme for MMR WiMAX network that can reduce the multi-hop delay and efficiently utilizes the available resources in order to satisfy the QoS requirements of end SSs?
- How to develop a transmission control mechanism for MMR WiMAX network that is able to decrease timeout possibilities and provide transmission rates fairness among SSs at different hop levels in order to satisfy the QoS requirements?
- How to develop an error control scheme that is able to optimize ARQ parameters adjustment for multi-hop system in order to enhance error probability, error recovery time and efficiently utilizing the available resources?

1.3 Problem Statement

In MMR WiMAX network, the insertion of RS to relay data packets between BS and SS introduces delay that is proportional with the number of hops, hence resulting in performance degradation. Additionally, variation of transmission delay affects transmission rate fairness among SSs at different hops. Link layer transmission time of ARQ packets is also affected by the hop level which causes rapid fluctuation of TCP segment delivery time that leads to frequent timeout occurrences in MMR WiMAX network. This would cause long recovery time and deficient utilization of the available resources. Therefore, there is a need for resource management scheme to be able to reduce the delay of relaying data packets across multiple hops and enhance the resource utilization. In addition, new transmission control that reduces the timeout occurrences; provides fairness among different hops and QoS requirements should be considered. Lastly, the error control schemes need to be optimized in order to achieve reliable data transmission over MMR WiMAX network.

1.4 Research Objectives

To enhance data transmission over MMR WiMAX network, improvement on the resource management schemes, transmission control and error control have to be conducted. Therefore, the objectives of this thesis are:

- To design resource management schemes for MMR WiMAX network that is able to decrease the delay of relaying data packets across multiple hops, and achieve fair and efficient utilization of the available resources.
- To design transmission control scheme that reduces timeout occurrences and improves transmission rates of TCP traffic over MMR WiMAX network.
- To design an error control scheme for MMR WiMAX network that reduces packet error rate and end-to-end transmission delay.

1.5 Methodology

The methodology used in the research process has been to start with a literature survey of the problem, analyse related problems and thereafter formulate a mathematical model of the problem. Then we use key defining features of the model to obtain an efficient solution. The solution is further validated and refined through simulation work on numerous and varied scenarios. The results obtained from the proposed solution are then compared with the other existing solutions to verify its efficiency. Background on each of the addressed problems is provided in the proceeding sections. For our work on enhancement of data transmission for MMR WiMAX networks, we used a resource management, transmission control and error control schemes, the design concepts of which are available in Chapter 3.

1.6 Research Scope

The scope of the thesis mainly focuses on improving the performance of data transmission over MMR WiMAX network. The developed schemes are applied at a three hops MMR WiMAX network. The type of RS used to relay data packets from MMR-BS to end SS is Non Transparent RS (NT-RS). The type of traffic considered in this thesis is nrtPS with minimum reserved rate and maximum sustained rate QoS. The proposed schemes are evaluated using a simulation code written in MATLAB. The developmental phase has been divided into three main parts. The details of each phase are as follows:

- **Design of Resource Management Scheme for MMR WiMAX Network**

The design of the resource management scheme composes of four phase namely; frame structure for NT-RS, uplink bandwidth demand estimation for NT-RS, Call Admission Control (CAC), and scheduling algorithm. In all cases, flow chart, state diagrams, and pseudo code have been used extensively to describe the various modules and schemes used to enhance the data transmission over MMR WiMAX network. The mathematical description of the various resource management schemes has been included as well. Lastly, the effect of the resource management schemes on the TCP traffic performance is analysed through simulation work. The proposed resource management schemes have been developed in the simulation environment. The TCP traffic is sent over wireless MMR WiMAX network based on IEEE 802.16j MAC and physical layer. The performance of the proposed schemes have been studied and compared with the other schemes in the literature. The performance is compared in terms of access and relay zones capacity utilization, delay of relaying the data packets across multiple hops, and link layer and TCP throughput and goodput of SS at different hop levels.

- **Design of Transmission Control Scheme for MMR WiMAX Network**

The design of the transmission scheme consist of two phase namely; Cross Layer Transmission Control (CLTC), and Retransmission Timeout (RTO) smoothing scheme. Cross layer design concept is utilized here to extract the required parameters and inform the sender with the transmission control decisions. The CLTC uses QoS requirement, Round Trip Time (RTT) and the TCP segment size in order to determine the transmission control parameters. The state diagrams, timing diagrams and block diagrams are used to describe the functionality of the schemes used to optimize the TCP performance over the MMR WiMAX network. Lastly, the improvements of TCP traffic performance when the proposed schemes are applied are analysed through a simulation work. The proposed transmission control schemes are implemented into the simulation environment. The MMR WiMAX network based on IEEE 802.16j MAC and physical layer is injected with TCP traffic. The performance of the proposed schemes have been studied and compared with the other schemes in the literature. The performance of the proposed scheme is compared in terms of the allocated resources utilization, TCP throughput, TCP goodput, number of timeouts occur and congestion window development of SS at different hop levels.

- **Design of Error Control Scheme for MMR WiMAX Network**

The error control schemes are designed in two phases; Cross Layer Error Control (CLEC) to optimize the ARQ parameters for MMR WiMAX network and resource aware Adaptive Modulation and Coding (AMC). In the first phase, the hop level, link status, QoS requirements, and timeout timer parameters are considered to select the suitable ARQ parameters. The second phase design an algorithm applied to the NT-RS to determine a suitable modulation schemes that able to minimize the error rate of packets relayed across multiple hops. The functionality of the proposed schemes is presented using state diagram, pseudo code, timing diagram and block diagrams. The effectiveness of the error control scheme is analysed through simulation work. The proposed schemes are implemented to the MMR WiMAX network and the TCP traffic is applied. The performance of various parameters on link layer and TCP performance are tested sequentially. This allows critical analysis on each parameter which contributes toward improving system performance. The performance is compared in terms of the utilization of the allocated resources to each SS, link layer throughput, link layer goodput, TCP throughput and TCP goodput of SS at different hop levels.

1.7 Contributions

This research presents significant algorithms to enhance the reliable data transmission techniques performance over MMR WiMAX networks.The contributions of this work are summarized as follows:

- The proposed new multi-frame (NMF) structure has reduced the forwarding delay from (2*Q-1) to Q, where Q is the number of hops as compared to multi-frame (MF) structure and it maintains the system capacity as well.
- The designed uplink bandwidth demand estimation for NT-RS reduces the delay of the bandwidth request as compared to bandwidth request aggregation scheme which improves the link layer and TCP traffic performances.
- The proposed QoS architecture and algorithm which considers the hop level in the queuing and forwarding decision provides fairness among different hops and effective utilization of the available resources.
- The proposed RTO smoothing scheme minimizes the timeout occurrences due variable packet transmission time.
- The developed Cross Layer Transmission Control (CLTC) scheme for MMR WiMAX network enhances the transmission rates of SSs at different hops in order to satisfy the required QoS requirement.
- The developed Cross Layer Error Control (CLEC) scheme improves the data transmission over MMR WiMAX network performance through the reduction of end-to-end transmission delay and packet error rate as well as the efficient utilization of the available resources.

- The proposed resource aware Adaptive Modulation and Coding (AMC) decreases the percentages of link layer packets in error at the second and third hops and hence improves the link layer and TCP performances.

1.8 Thesis Structure

This thesis composes of seven chapters organized as follows:

In Chapter 2, recent development and advancement in the field of WiMAX standards, the features of the IEEE 802.16j MMR WiMAX and the reliable data transmission techniques related to the scope of the research are discussed. The existing techniques used to improve the performance of data transmission over wireless are analysed and their limitations are highlighted.

Chapter 3 deals mainly with the system design and architecture of the proposed schemes. The flow chart, state and timing diagrams describe the methodology, techniques and approach used for the proposed schemes. The topics discussed include the research framework, the proposed resource management, transmission control, error control schemes for MMR WiMAX networks, and the network architecture and simulation.

Chapter 4 focuses on the resource management design concepts and evaluation for MMR WiMAX networks. This chapter explains the proposed NMF frame structure, relay link bandwidth demand estimation algorithm, scheduling and call admission control algorithms. Lastly, the performance evaluations of the proposed schemes are discussed.

Chapter 5 elaborates on the design of the proposed transmission control. In which, the details of cross layer transmission control and RTO smoothing scheme are discussed. Next, the performance evaluations of the proposed scheme are presented and analysed.

Chapter 6 discusses the design concepts and evaluation of the proposed error control mechanisms. The proposed hop aware ARQ parameters adjustment mechanisms, resource aware AMC scheme and comparison of the effect of end-to-end and RS-ARQ on the TCP performance are discussed. Lastly, the performances of the proposed schemes are evaluated.

Finally, chapter 7 concludes the thesis and suggests future research directions.

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APPENDIX A

A.1 List of Related Publications

- Fath Elrahman Ismael, Sharifah K. Syed-Yusof, Mazlan Abbas, and Norsheila Faisal, ***QoS aware Transmission Control Scheme for Multi-hop WiMAX Networks,*** submitted to International Journal of Communication Systems (IJCS) (accepted to be published with minor correction) (IF of 0.229).

- Fath Elrahman Ismael, Sharifah K. Syed Yusof, Mazlan Abbas, Norsheila Faisal, N.Muazzah and R.Rashid, ***Frame Structure for MMR WiMAX Networks*****,** submitted to International Journal of Physical Science (under review) (IF of 0.51).

- Fath Elrahman Ismael, Sharifah K. Syed Yusof, Mazlan Abbas, and Norsheila Faisal, ***Hop aware ARQ for MMR WiMAX Networks***, submitted to European Journal of Scientific Research (accepted for publication).

- Fath Elrahman Ismael, Sharifah K. Syed Yusof, Mazlan Abbas, and Norsheila Faisal, ***Hop Aware Scheduling Algorithm for TCP Performance Enhancement in MMR WiMAX Network***, Accepted to be published at Journal Teknologi.

- Fath Elrahman Ismael, Sharifah K. Syed-Yusof, and Norsheila Faisal, ***Bandwidth Grant Algorithm for Delay Reduction in IEEE 802.16j MMR WiMAX Networks,*** International Review on Computers and Software (I.RE.CO.S), Vol. 5,N. 2, March 2010.

- Fath Elrahman Ismael, Sharifah K. Syed Yusof, and Norsheila Faisal, ***An Efficient Bandwidth Demand Estimation for Delay Reduction in IEEE 802.16j MMR WiMAX Networks***, International Journal of Engineering (IJE), Vol.3 Issue 6, Jan. 2010.

- Fath Elrahman Ismael, Sharifah K. Syed-Yusof, and Norsheila Faisal, ***Reduction of the Bandwidth Request Delay in IEEE 802.16j MMR WiMAX Networks*** , ICACSIS 2009, Jakarta 7 to 8 December 2009, ISSN:2006-1796, p 295-299.

- Fath Elrahman Ismael, Sharifah K. Syed Yusof, Mazlan Abbas, Adnan Shahid Khan, and Norshiela Fisal, ***Throughput Enhancement in MMR WiMAX IEEE 802.16j Networks***, 3rd International Graduate Conference on Engineering, Science, and Humanities, Johor Bahru, 2-5 Nov. 2010.

- Fath Elrahman Ismael, Sharifah K. Syed Yusof, Mazlan Abbas, Adnan Shahid Khan, and Norshiela Fisal, ***TCP Packet Loss Reduction for MMR WiMAX Networks using Cross Layer Design***, 3rd International Graduate Conference on Engineering, Science, and Humanities, Johor Bahru, 2-5 Nov. 2010.