Abstract

A tight coupling cooperation scheme for WiFi/WiMAX networks with QoS provisioning has been proposed in this paper. A new WFW (WiMAX for WiFi) module which enables WiMAX fulfill the procedure of bandwidth request-confirm-grant for WiFi was described with a modified MAC layer of which MSH-DSCH (Mesh Distributed control message) renewed, and thus overhead of interacting of WiFi control message was eliminated. The schedule is then evaluated through simulations in two typical transmission scenarios. Numerical results show that more effective WiFi/WiMAX heterogonous networks which offer QoS guarantees are obtained with the utilization of the scheme. The efficiency of WiFi Mesh networks increase sharply without obvious decrease of WiMAX performance.

Keywords: tight cooperation, WiMAX for WiFi, QoS provisioning.

1 Introduction

Broadband wireless communication has been a promising area compares to the conventional wireless networks over the last decade [1]. Also the technique has diversified different Radio Access Technologies (RATs) such as WiMAX, WiFi etc. [2]. Hence there has been a heterogeneous network, so called multiple radios access technology cooperation catch our attentions. The heterogeneous networks make an expecting tendency that the nodes within which could be embedded with multiple RATs. The nodes mentioned above could also work simultaneously in different networks so as to acquire a better QoS, enlarge the range of the network or enhance the reliability of data transmissions. While these advantages make a limited progress in the simply
network of which different RATs work independently, a further progress could achieved by the use of the cooperation of different RATs in a single heterogeneous wireless network.

Generally speaking, when concerning RAT cooperation, two possible classifications could be available: loosely RAT cooperation and tightly RAT cooperation. A loosely cooperation is often designed by a coordinate MAC layer which could effectively allow fast switching between different RATs which is also transparent to the upper layer [3]. For example, in [4], the author proposes a loose cooperation scheme between WiMAX and WiFi in the Airtime-based module which can make the cooperation strategy and control the RATs through the collection of each RAT’s information. And in [5] a simple integration of WiFi/WiMAX network model was studied, the performance of the heterogeneous network was improved to some degree, while details of the model designs were not given. The loose cooperation has its own limitation as we couldn’t ensure the accuracy of the collected information and the time delay of make the proper strategy lose its own timelessness. Tight cooperation, however, could relate RATs and MAC straightly, so as to make more effective ways to take the proper strategies without decreasing the network’s performance obviously. In [6], the author introduces a cooperation scheme between WiFi and WiMAX. The scheme could make WiFi offload some WiMAX traffic which is limited and intelligible. Further solutions should be given in order to get a better use of the tight cooperation scheme’s advantages. Authors in [7] give a really novel scheme for the integration of the WiMAX and WiFi architecture which utilize the tight cooperation scheme. However, the main structure of it is similarly to a middleware and thus the representation could be limited in to some degree. A specific module and more particularly schemes could be given in order to improve the performance of the networks ulterior.

Compared to WiFi network, WiMAX network has some significant advantages in the following aspect: A better network efficiency due to the WiMAX’s Time Division Multiple Access (TDMA) Method which makes the exchange of the control message and the date delivery more convenient; The elimination of influence towards the data sub-frame by concentrating the control message in the control sub-frame. The transmission was predicted beforehand so frames come later would not hand in again. Furthermore cooperation between WiFi and WiMAX could achieve obvious benefits due to the additional spectrum resource in heterogeneous networks, the negotiating scheme, of which could also reduce the collision and interference probabilities that may occur between different RATs. In [8], the author focus on the significant gain that could be reaped in integrated networks of WiMAX and WiFi, then gives a detailed analysis in diverse aspects. Thus proves the significant and promising potential in this field.

In this paper, we propose a tight coupling cooperation scheme for the WiFi/WiMAX heterogeneous networks. A new WiMAX for WiFi (WFW) module was developed to share the WiMAX time slot for WiFi. Information exchanges between the WiFi and WiMAX was also achieved by employing the WFW module. In addition, a modified MSH-DSCH (M-DSCH) was designed to consult for both WiFi and WiMAX about bandwidth request information. By making use of different RATs, WiMAX RATs could take up the request-confirm-grant procedure for the WiFi RATs; as a result, WiFi control message was eliminated. Specially, the system used by WFW module in reconciling the communication between WiFi and WiMAX is relied on the modified M-DSCH which was off interference as WiFi and WiMAX’s own standard keep the original being. The QoS and higher throughput for the whole heterogeneous network could also be guaranteed because of the tightly coupled cooperation.

The remainder of this paper is organized as follows. The M-DSCH was presented in Section 2. Section 3 introduces the detailed description of the WFW module and the tight coupling cooperation system. Section 4 shows the numerical results from the two typical scenarios using the proposed scheme. Section 5 draws a summary of the paper and the intended direction of the future work.
2 M-DSCH Message Scheduling

This section is started with the description of the M-DSCH message structure and then provides
the performance analysis of the M-DSCH and the heterogeneous network with the M-DSCH in
terms of theory.

2.1 Structure of M-DSCH

The tight coupling cooperation scheme could be fulfilled by the WiMAX’s replacing for WiFi
in the bandwidth request-confirm-grant procedure. Here, an assumption was made that the
neighbor of WiFi RATs is the subset of the WiMAX RATs. The assumption can be proved by
the following theorem.

**Theorem 1.** The neighbor of WiFi RATs is the subset of the WiMAX RATs.

Proof. Suppose the effective range of the WiFi and WiMAX RATs are \( R_{WiFi} \) and \( R_{WiMAX} \), the
neighbor subset of them is \( S_{WiFi} \) and \( S_{WiMAX} \). Assume that the signal’s transportation was not
interfered by the wireless environment nearby. As a result the range of WiFi and WiMAX must
be a concentric circles, and \( R_{WiFi} < R_{WiMAX} \). And when we considering the same facilities,
the subset of their neighbor must have the relations as follows \( S_{WiFi} \subseteq S_{WiMAX} \). So far the
theorem 1 was proved. \( \square \)

Theorem 1 was the theoretical basis of the M-DSCH message. Table 1 illustrates the M-
DSCH message structure to realize the tightly coupled cooperation scheme.

The item marked by a “*” was the original item which also included in the original MSH-
DSCH. When we use distributed coordination function (DCF) in the traditional WiMAX net-
works. Grant/Request Flag was permanently fixed by a zero. Signifying signal contains MSH-
DSCH Request_IE(), MSH-DSCH Grant_IE() simultaneously. The parameters we need to know
are the No.Request, No.Availabilities, and No.Grants represents the numbers of the Request_IE,
Available_IE, and Grant_IE respectively. The data structure and the other parameters’ conno-
tation could refer to the IEEE Std 802.16-2004 [9]. Additional items in the M-DSCH message
are WiFi Grant/Request Flag, No.WiFi Request, No.WiFi Availabilities, and No.WiFi Grants.
Similarly when we use DCF, the WiFi Grant/Request Flag was fixed a zero permanently, rep-
resents that the signifying signal could also request, confirm and grant for the WiFi RATs,
WiFi Grant/Request Flag, No.WiFi Request, No.WiFi Availabilities, and No.WiFi Grants rep-
resents the numbers of the Request_IE, Available_IE, and Grant_IE which has the identical data
structure of the WiMAX RATs.

2.2 Performance Analysis of M-DSCH

2.2.1 Analysis of Signaling Size

M-DSCH control signal message should transmit trough 7 OFDM symbols without split into
segments. The size of the No.Grants was 6bits in the original DSCH, while it is changed into
to 5 bits in the M-DSCH. The size of No.WiFi Grants is fixed in a 5 bits size. In order to meet
the demands with the requirement of the signaling transmission delay, the maximum figure of
MSH-DSCH_Grant_IE() was decrease from the original 63 to 31. The following Theorem refthe:2
proves that when the max figure of M-DSCH’s Grant_IE is fixed 31, the protocol will perform
normally.

**Theorem 2.** It was sufficient when the No.Request is 4 bits and No.Grants is 5 bits in the
M-DSCH.
### Table 1: Structure of WIMAX Mesh MDSCH Message

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSH-DSCH_Message_format()</td>
<td></td>
</tr>
<tr>
<td>* Management Message Type = 41</td>
<td>8 bits</td>
</tr>
<tr>
<td>* Coordination Flag</td>
<td>1 bit</td>
</tr>
<tr>
<td>* Grant/Request Flag</td>
<td>1 bit</td>
</tr>
<tr>
<td>* Sequence counter</td>
<td>6 bits</td>
</tr>
<tr>
<td>* No. Requests</td>
<td>4 bits</td>
</tr>
<tr>
<td>* No. Availabilities</td>
<td>4 bits</td>
</tr>
<tr>
<td>* No. Grants</td>
<td>5 bits</td>
</tr>
<tr>
<td>WiFi Grant/Request Flag</td>
<td>1 bit</td>
</tr>
<tr>
<td>* reserved</td>
<td>2 bits</td>
</tr>
<tr>
<td>No. WiFi Requests</td>
<td>4 bits</td>
</tr>
<tr>
<td>No. WiFi Availabilities</td>
<td>4 bits</td>
</tr>
<tr>
<td>No. WiFi Grants</td>
<td>5 bits</td>
</tr>
<tr>
<td>reserved</td>
<td>3 bits</td>
</tr>
<tr>
<td>if (CoordinationFlag == 0)</td>
<td></td>
</tr>
<tr>
<td>* MSH-DSCH_Scheduling_IE()</td>
<td></td>
</tr>
<tr>
<td>* for (i = 0; i &lt; NoRequests; + + i)</td>
<td></td>
</tr>
<tr>
<td>* MSH-DSCH_Request_IE()</td>
<td>16 bits</td>
</tr>
<tr>
<td>* for (i = 0; i &lt; NoAvailabilities;</td>
<td></td>
</tr>
<tr>
<td>* MSH-DSCH_Availability_IE()</td>
<td>32 bits</td>
</tr>
<tr>
<td>* for (i = 0; i &lt; NoGrants; + + i)</td>
<td></td>
</tr>
<tr>
<td>* MSH-DSCH_Grant_IE()</td>
<td>40 bits</td>
</tr>
<tr>
<td>for (i = 0; i &lt; NoWifiRequests; + + i)</td>
<td></td>
</tr>
<tr>
<td>MSH-DSCH_Request_IE()</td>
<td>16 bits</td>
</tr>
<tr>
<td>for (i = 0; i &lt; NoWifiGrants; + + i)</td>
<td></td>
</tr>
<tr>
<td>MSH-DSCH_Availability_IE()</td>
<td>32 bits</td>
</tr>
<tr>
<td>MSH-DSCH_Grant_IE()</td>
<td>40 bits</td>
</tr>
</tbody>
</table>

**Proof.** M-DSCH fulfill the bandwidth require-confirm-grant through the 3-shake hands procedure. Each bandwidth request message corresponds with a bandwidth grant message. When the bandwidth requester gets the grants message, it returns confirm information which is same as the grant information in numbers. Thus, each grant information correspond with a confirm information. When the network runs long enough, the sum of the confirm message and the grant message should be twice as much as the request information. The max figure of No.Request is 15 because the message is 4bits, it means that a DSCH message cold load 15 bandwidth request messages. Hence the number related confirm and grant message should be at least 30. When the No.Grants takes 5bits, the max figure of it is 31 which are more than the required 30. So Theorem 2 is rational.

### 2.2.2 Analysis of Transmission Delay

Suppose the maximum length of the M-DSCH is $S_{MAX}$. Then Equation 1 is established as follows.
\[ S_{\text{MAX}} = \sum S_{\text{Param}} + \max(\text{No Availabilities}) \cdot S_{\text{Availability_IE}} + \max(\text{No WiFi Availabilities}) \cdot S_{\text{Availability_IE}} + \max(\text{No WiFi Request}) \cdot S_{\text{Request_IE}} + \max(\text{No WiFi Grant}) \cdot S_{\text{Grant_IE}} \]  

(1)

Where \( S_{\text{MAX}} \) is the M-DSCH’s length of the maximum parameters. When compute with the existing parameters, the result of \( S_{\text{MAX}} \) is 1263 Bytes. Suppose the original DSCH message length is \( S'_{\text{MAX}} \), then Equation 2 could be formulated as follows.

\[ S'_{\text{MAX}} = \sum S_{\text{Param}} + \max(\text{No WiFi Availabilities}) \cdot S_{\text{Availability_IE}} + \max(\text{No WiFi Request}) \cdot S_{\text{Request_IE}} + \max(\text{No WiFi Grant}) \cdot S_{\text{Grant_IE}} \]  

(2)

Compute with the existing parameters, the size of \( S'_{\text{MAX}} \) is 1176 Bytes. So far a conclusion could be inferred that M-DSCH was 87 Bytes more than the DSCH. Through the equation about bandwidth and time delay, the requirement could be assured that MDSCH should transmit trough 7 OFDM symbols without split into segments. The frame design of the M-DSCH is reasonable.

2.2.3 Analysis of the WiFi and WiMAX Mesh Network Performance Using M-DSCH Message

Time slots are divided into frames in the WiFi MAC layer. In the WiFi and WiMAX tightly cooperation scheme, the \( n^{\text{th}} \) frame of WiFi starts from the \( n^{\text{th}} \) data sub-frame of WiMAX, and finish at the end of the \( (n+1)^{\text{th}} \) control sub-frame of WiMAX.

Figure 1: Demonstration of WiFi bandwidth request by WiMAX MAC

Figure 2.2.3 shows WiMAX MAC layer use the control sub-frame of the \( n^{\text{th}} \) and the \( (n-1)^{\text{th}} \) frame to reconcile the data transmission of WiFi and WiMAX in the \( n^{\text{th}} \) frame. Suppose the length of the WiMAX frame is \( l(s) \), the percentage of the control sub-frame is \( r \) (\( 0 < r < 1 \)), the length of the WiFi frame is the same \( l(s) \) as WiMAX. The \( r \) is changeable, when \( r = r_1 \) (\( 0 < r_1 < 1 \)), if there are sufficient control sub-frames to reconcile the bandwidth requirement of the WiMAX and WiFi, then the length that could be scheduled in each WiFi frame \( l_s \) is described in the following Equation 3:

\[ l_s = r_1 l + (1-r_1)l = l. \]  

(3)

Then the performance efficiency of the WiFi mesh is \( \delta \) theoretically, then \( \delta = l_s/l = 100\% \). Namely WiFi mesh network could reach the maximum throughput in theory.
The increasing number of the signaling message of M-DSCH could affect the performance of WiMAX mesh network. Then we will analysis the effects of the change above. Imagine a network with \( K \) nodes, \( N_i \) represents the node \( i \) (\( i = 1, \ldots, K \)). M-DSCH runs only for WiMAX. In a sequential \( \xi \) scheduler control frames, node \( N_i \) occupies \( n_i \) control frames, which means a total \( n_i \) transmits chances, here comes the Equation 4.

\[ \Phi(rl) \] is transmits chances of control frames which is \( rl \) in length, then \( \Phi() \) has a propriety like this, \( x\Phi(y) = \Phi(xy) \). Equation 4 based on an assumption that the control frames was saturated, which means the transmit chances could be utilized completely.

\[ \sum_{i=1}^{K} n_i = \xi\Phi(rl). \tag{4} \]

Suppose that \( \xi \) series scheduler control frames make the bandwidth request simultaneously, and then the M-DSCH messages transmit through node \( N_i \) could be divided into \( \alpha \) M-DSCH messages which merely contain the 3-shook hands procedure information for WiMAX, \( \beta \) M-DSCH messages which contains the grant, confirm messages for WiFi and WiMAX simultaneously, \( \gamma \) M-DSCH messages which merely contain the 3-shook hands procedure information for WiFi. Because the WiMAX and the WiFi bandwidth arrangement are off interference, then \( \alpha + \beta = n_i \) was inferred. If \( P \) is the ratio that M-DSCH messages which merely contain the 3-shook hands procedure information for WiFi of the total M-DSCH messages in the same nodes, then Equation 5 is conducted.

\[ P = \gamma/(\alpha + \beta + \gamma) = \gamma/(n_i + \gamma). \tag{5} \]

When the scheme uses for WiMAX only, node \( N_i \) has \( n_i \) transmit chances. When using for both WiMAX and WiFi in order to fulfill the same requirement, suppose the node \( N_i \) has \( n'_i \) transmit chances, \( n'_i \) could be conducted as Equation 6.

\[ n'_i = n_i/(1 - P). \tag{6} \]

Then the total transmission chances of all nodes in the network environment are as the following Equation 7:

\[ \sum_{i=1}^{K} n'_i = \sum_{i=1}^{K} n_i/(1 - P) = 1/(1 - P) \sum_{i=1}^{K} n_i = 1/(1 - P)\xi\Phi(rl) = \xi\Phi(rl/(1 - P)). \tag{7} \]

In order to meet the total requirement of all the nodes in the tight coupling cooperation scheme, the percentage of the control sub-frame should increase from \( r \) to \( 1/(1 - P) \). Compared with the total WiMAX environment, the total decreasing throughput is \( \tau \):

\[ \tau = ((1 - r) - (1 - r/(1 - P)))/(1 - r) = r/(1 - r)(1/(1 - P) - 1). \tag{8} \]

Since \( r \) is a constant, \( P \) and \( \tau \) are of the positive pertinence, a conclusion could be concluded that when \( P \) becomes smaller, the loss of the WiMAX performance becomes fewer. When \( P \) was 0, then \( r \) is zero, and WiMAX performance is lossless. Hence, reducing the percentage of the M-DSCH messages which service for WiFi only was the key point when we designing the tightly coupling cooperation system.
3 Designing of the Tight Coupling Cooperation System

This section commences by giving the description of WiMAX 3-shook hands procedure so as to apprehend the following proposed system. Then a detailed description about the designation of the tightly coupling cooperation system is introduced. The ultimately goal in designing the system is to decrease the figure of P mentioned in the preceding section.

3.1 DSCH Handshaking Procedure in WiMAX

Figure ?? is a simplified WiMAX MAC layer; it is composed by the core disposal WiMAX MAC Module (WMM), Bandwidth Request Queue (RQ) which accords to the First in First out (FIFO) principle, the Availability Queue, and the Grant/Confirm Queue which also accords to the FIFO principle. WiMAX MAC layer use a feigned random algorithm to provide the transmission chance for the DSCH message, the detail of the algorithm could refer to [9]. The DCF process as the following description:

• When receives a bandwidth request from the other nodes, WMN compute the bandwidth grant information (Grant) bases on the Available information in AQ, then insert Grant into GCQ (Grant Confirm Queue).

• When receives a Grant in which destination address is the same as the node itself, update AQ (Availability Queue) and generate the Confirm information and insert into the GCQ. Simultaneously inform the Node combined with Grant information to transmit data in the allocated minislot. If the received destination address if different from the nodes itself, update the AQ only.

• When a node receives Confirm information, update the AQ.

• When the nodes get the transmission chances of the DSCH, generate the DSCH information firstly, WMN fills the parameters' domain and MSH-DSCH_Schedulin_IE(), RQ, AQ, GCQ fills the MSH-DSCH_Request_IE(), MSH-DSCH_Availability_IE(), MSH-DSCH_Grant_IE() respectively. DSCH will transmit during the beginning of the transmission chance.

How to make a decision for the bandwidth allocation is not the key point of our work, so unnecessary details will not be given. The available time slots and the time slot duration information is recorded in the data structure of AQ, but the specific design is not given in [9]. In the supposed system, linked list is chosen to achieve the storage function. Using the procedures above, WiMAX MAC could fulfill the 3-shook hands procedure of DSCH and assure the data sub-frame transmits successfully without any collision.
3.2 Implementation of WiFi and WiMAX Tight Coupling Cooperation System

3.2.1 Design of the System

Figure 3.2.1 gives the detail implementation of WiFi and WiMAX tight coupling cooperation system. A WFW module is set up between the MAC layer of WiFi and WiMAX which is utilized to fulfill the requirement of the system. The module was composed as follows.

![Diagram of WiFi and WiMAX cooperation scheme]

- Information Sharing Module: the sharing information is showed in the Table II, WiFi and WiMAX synchronized through the acquired timing information. WiFi shares the Links ID, Neighbor MAC address, minislot Number and other related information with WiMAX. Hence, WiMAX could take the WiFi request-grant-confirm procedure. The Data sub-frame of WiMAX is divided into 256 minislots. Supposing each WiFi frame has minislots, $\sigma$ could be computed as the Equation 9.

$$
\sigma = \text{floor}(l/((1-r)l/256)) = \text{floor}(256/(1-r)).
$$

- WFW processing module: this module is used to receive the mutual require-grant-confirm information between the WiMAX and WiFi MAC layer, and then delivers the related information to the other side. When generating the M-DSCH, the module is used to fill the related data structure.

- WiFi Request Queue (WRQ), WiFi Available Queue (WAQ), and WiFi Grant/Confirm Queue (WGCQ): WRQ is used to store query information generated by WiFi MAC layer; WAQ is used to record the location information of the available time slots; WGCQ is used to store the grant and confirm information in responding to the neighbors.

3.2.2 Working Procedure of the System

The proposed system works as the following procedures:

- When a bandwidth request is generated from the WiFi MAC layer, the message is submitted to the WFW processing module. The WFW module then inserts it into the WRQ.

- When the WiMAX MAC layer receives WiFi Grant information, it generates bandwidth grant information named Grant based upon the Information Sharing module and then inserts it into the WGCQ.
Table 2: Sharing Information between WIFI MAC and WIMAX MAC

<table>
<thead>
<tr>
<th>802.11 MAC</th>
<th>802.16 MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link IDs</td>
<td>Current frame number</td>
</tr>
<tr>
<td>Neighbor MAC address</td>
<td>Frame start time</td>
</tr>
<tr>
<td>Availabilities information</td>
<td>Frame duration</td>
</tr>
<tr>
<td>Minislot Number $\sigma$</td>
<td>Data subframe start time</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Minislot length</td>
</tr>
</tbody>
</table>

- When WiMAX MAC layer receives the WiFi Grant information, the layer will submit it to the WFW module, if the information’s destination address is exactly the address of the WiFi MAC layer. Then submits the Grant to the WiFi MAC, WiFi MAC layer will inform the related connection to transmit data in the stipulated minislots. WFW updates the WAQ and generates the confirm information which is inserted into the WGCQ. If the destination address is not the address of the WiFi MAC layer, update the WAQ.

- When WiMAX receives the WiFi Confirm information, it will submit the information to the WFW processing module, then updating the WAQ through the Confirm information.

- When WiMAX gets the transmission change of the M-DSCH and generates the M-DSCH messages, WiMAX MAC will fill the related domains of the WiMAX. WFW update the domains of WiFi, the MSH-DSCH Request IE(), MSH-DSCH Availability IE(), MSH-DSCH Grant IE() was filled by the WRQ, WAQ, WGCQ respectively. M-DSCH starts transmission from the beginning of the transmission chances.

3.2.3 Performance Analysis of the System

The performance analysis of the system is as the Theorem 3.

**Theorem 3.** The tightly coupling cooperation scheme of the WiMAX and WiFi draws lossless impacts to the original WiMAX scheme.

**Proof.** Drawing from the cooperation scheme, when WiFi MAC layer generates the bandwidth Request, WFW module will put it into the WRQ. Imagine the WRQ’s length is infinity, then WiMAX will obtain the M-DSCH transmission chances using the feigned random algorithm based on the request, grant, confirm requirements. When generating the M-DSCH messages, MSH-DSCH Request IE() and MSH-DSCH Grant IE() in the M-DSCH contains one or more effective information then $\alpha + \beta + \gamma = \alpha + \beta$, then $\gamma = 0$ and $P = 0$. So the Theorem 3 is proved.

4 Performance Evaluation Through Numerical Simulations

In this section, we evaluated the performance of the proposed scheme through simulations over NS-2 [10]. Based on the platform, two typical scenarios are carried out. The simulation environment and the parameter settings are described firstly, and then simulation results and the performance analysis are presented in the later part of the section. The two scenarios are evaluated in regular sequence.
4.1 Network Topology and Parameter Settings

4.1.1 Implementation of the Modules

We implement following modules in the NS2 platform: WiMAX MAC modules which support the cooperation mode and noncooperation mode, noncooperation mode is based on the OFDM physical layer and its modulation mode which could also support the feigned random algorithm in transmitting signaling messages between DSCH, NCFG and NENT and data frames between nodes. On the bases of the noncooperation mode, cooperation mode could generate, send, receive the M-DSCH messages, and support in processing messages with the WFW modules; WFW processing modules which works as the description in the former section; Modified WiFi MAC module, which support the cooperation mode and the DCF mode. The modified module also allows the WiFi MAC to make bandwidth require and process signaling interaction and the time division data transmission with the WFW module.

4.1.2 Network Topology

In order to analysis the performance of the proposed scheme, 2 scenarios are introduced in this paper:

- Fixed topology of double data flows in a single hop. The network contains 2 fixed nodes; each node is embedded with WiFi and WiMAX RATs. When we take the noncooperation mode: WiFi and WiMAX works independently, WiFi occupancy rate of the channel is larger, the throughput and the network efficiency work nearly the maximum value in theory. While the WiMAX performance will suffer a sharply decrease compared to the network using the cooperation mode.

- Random topology of multi-hop and multi flows. Several nodes are randomly distributed in the scenario; each node is embedded with WiFi and WiMAX RATs. In this scenario, the average throughput and the efficiency comparisons between WiFi and WiMAX will help in analyzing the performance gain in our proposed system.

4.1.3 Parameter Settings

In order to measure the performance of WiFi and WiMAX respectively, each node is configured with two constant CBR flows of witch the packet length is 1000 Bytes and packet generation interval is 0.005s, each RAT serves one CBR flow. The parameters of WiFi are set as follows: the signal range of RTS/CTS and data is 550m, 250m respectively. A 50 length of queue is used with Physical layer, of which the highest transmit rate is 1Mbps. Modified WiFi layer does not contain the RTS/CTS and ACK procedure, the other parameters is set upon the [9].

The parameters of WiMAX are set as follows: the queue length of WiMAX MAC layer is set with a 50, the percentage of the control sub-layer is 30%, the Scheduling frames is with a 1 set which means 4 scheduling frames emerges during every two control frames. The protocol of the physical layer is using the OFDM and with a 5MHz bandwidth. The band is set to 3.5GHz; Modulation mode of the control sub-frame is set with the OFDM\_QPSK\_1\_2 according to [9], data transmission modulation mode is set with the OFDM\_16QAM\_1\_2.

4.2 Simulation Results

4.2.1 Performance Evaluation in Single Hop Scenario

The scenario contains two nodes within each other's signal coverage. Figure 4.2.1 depicts the average throughput in the single hop scenario, of which the data flow starts at 30s and end at
Throughput of WiFi mesh in single hop scenario

(b) Throughput of WiMAX mesh in single hop scenario

Figure 4: Average throughput in single hop scenario

130s. Solid points in the Figure 4.2.1 represent the average throughput in the following 10s from time point it correlates. Fig 4(a) shows the WiFi performance comparison between cooperation and noncooperation scheme. When using the DCF mode, the average throughput is 0.77Mbps. Since no rivals and interference in the scenario, 0.77Mbps is the max throughput in the 802.11 RTS/CTS procedure. And the efficient of the scenario is 0.77Mbps/1Mbps*100%=77%, which is conform to the analysis in the preceding section. When using the cooperation scheme, the average throughput is 0.96Mbps, the network efficient is 0.96Mbps/1Mbps*100%=96%, the network efficient is approximate to 100%. The 4% loss is due to the inefficient use of the mini-slot during the simulation which could be solved by constraining the length of the data flow. The result shows the efficiency of the proposed scheme.

Figure 4(b) shows the WiMAX performance comparison between cooperation and noncooperation scheme. When using the noncooperation scheme, the average throughput of the network is 1.5248Mbps; while using the cooperation scheme, the average throughput of the network is 1.5244Mbps with a deviation of 0.0026%. Hence, the proposed scheme maximizes the throughput and the network efficiency of the WiFi Mesh, assured a nearly lossless WiMAX Mesh network.

4.2.2 Performance Evaluation in the Random Topology

The scenario contains 10 nodes, distributed randomly in a 1000m*1000m area, with 4 CBR flows transmitting simultaneously. Simulation results are showed in the Figure 4.2.2, the data flow similarly starts at 30s and end at 130s. The solid points in the figure are the same as the points defined in the preceding parts. Figure 5(a) is the shows the comparison between cooperation and noncooperation scheme. When using the DCF mode the average throughput is 1.91Mbps in the noncooperation mode and 2.82Mbps in the cooperation mode. The performance of the network increased by (2.82Mbps-1.91Mbps)/1.91Mbps*100%=47.6%.

Figure 5(b) is the WiMAX performance comparison between cooperation and noncooperation scheme. When using the noncooperation scheme, the average throughput is 5.184Mbps; while using the cooperation scheme, the average throughput is 5.181Mbps. The performance of it decreases by a 0.057%. WiMAX suffer a subtle decrease nearly lossless as well.

The result of the simulations indicates that the proposed tight coupling cooperation scheme works in accordance with our anticipation that the scheme could guarantee the WiMAX RATs with a lossless performance and the WiFi RATs performance with an evident promotion. In the ideal network environment, the throughput and network efficient could reach the max value in theory.
5 Conclusion

The paper is concerned with a tight coupling operation scheme which could support the effective transmission among the WiMAX and WiFi RATs. In the proposed scheme, a WFW module is employed to do the bandwidth negotiation for WiFi. A novel M-DSCH was modified to support the WiMAX to fulfill the bandwidth request-grant-confirm procedure for WiFi. Numerical results have confirmed that the proposed scheme improve the performance of WiFi and draws subtle nearly a lossless inference to the original WiMAX performance. The QoS of the heterogeneous network is assured by the analysis above.

In the future, the author intends to examine the performance of the hybrid network in which the users are equipped with single WiFi RATs or WiMAX RATs or equipped with the two RATs simultaneously. Compatibility of the proposed scheme is another direction we will work on.

References


