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A Tight Coupling Cooperation Scheme in WiFi/WiMAX Heterogeneous Mesh Networks

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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, heterogeneous mesh networks.

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]. Heterogeneous networks make an expecting tendency that 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. In [3], the author explores the resource allocation of nodes in heterogeneous network which could solve some traditional wireless networks'resource allocation problem. Author in [4] introduces a Call-Level quality of Service vertical handoff algorithm which could be applied to heterogeneous wireless networks. A further progress could achieved by the use of different RATS in a single heterogeneous wireless network.

Generally speaking, when concerning RAT cooperation, two possible classifications are available. A loosely cooperation is often designed by a coordinate MAC layer which could effectively allow fast switching be- tween different RATs which is transparent to the upper layer [4]. For example, in [6], 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. Tight cooperation, however, could relate RATs and MAC straightly, so as to make more effective ways to take the proper strategies without decreasing the networks performance obviously. In [8], 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 schemes advantages. Specifically, a new module and more particularly schemes could be given in order to improve the performance of the networks ulterior.

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. 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; WiFi control message was eliminated. The QoS and higher throughput for the whole heterogeneous network could also be guaranteed because of the tightly coupled cooperation.

2 M-DSCH Message Scheduling

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.

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 networks. 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, Avaliable IE, and Grant IE respectively. The data structure and the other parameters' connotation could refer to the IEEE Std 802.16-2004 [3]. 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, represents 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 represents the numbers of the Request_IE, Avaliable_IE, and Grant_IE which has the identical data structure of the WiMAX RATs.

2.2 Performance Analysis of M-DSCH

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.

Analysis of Transmission Delay

Suppose the maximum length of the M-DSCH is S_MAX. When compute with the existing parameters, the result of S_{MAX} is 1263 Bytes. Suppose the original DSCH message length is

Table 1: Structure of WIMAX Mesh MDSCH Message

Syntax	Size	Syntax	Size
MSH-DSCH_Message format()			
{		* *if(CoordinationFlag == 0)*	
* Management Message Type = 41	8 bits	* MSH-DSCH_Scheduling_IE()	varialbe
* Coordination Flag	1 bit	* *for(i=0;i* $< No_{Requests}$*;++i)*	
* Grant/Request Flag	1 bit	* MSH-DSCH_Request_IE()	16 bits
* Sequence counter	6 bits	* *for(i=0;i* $< No_{Availabilities}$*;++i)*	
* No. Requests	4 bits	* MSH-DSCH_Availability_IE()	32 bits
* No. Availabilities	4 bits	* *for(i=0;i* $< No_{Grants}$*;++i)*	
* No. Grants	5 bits	* MSH-DSCH_Grant_IE()	40 bits
WiFi Grant/Request Flag	1 bit	* *for(i=0;i* $< No_{WiFi_{Requests}}$*;++i)*	
* reserved	2 bits	* MSH-DSCH_Request_IE()	16 bits
No. WiFi Requests	4 bits	* *for(i=0;i* $< No_{WiFi_{Availabilitiess}}$*;++i)*	
No. WiFi Availabilities	4 bits	* MSH-DSCH_Availability_IE()	32 bits
No. WiFi Grants	5 bits	* *for(i=0;i* $< No_{WiFi_{Grants}}$*;++i)*	
reserved	3 bits	* MSH-DSCH_Grant_IE()	40 bits
}			

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

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 our scheme, the n^{th} frame of WiFi starts from the n^{th} data sub-frame of WiMAX, and finishes at the end of $(n+1)^{th}$ control sub-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 as WiMAX. When $r = r_1(0 < r_1 < 1)$, the length that could be scheduled in each WiFi frame l_s is described in Equation 1:

$$l_s = r_1 l + (1 - r_1)l = l \tag{1}$$

Then the performance efficiency of the WiFi mesh is δ 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, here is the analysis of the effect. Imagine a network with K nodes, N_i represents the node $i(i \in \{1, .., K\})$. M-DSCH runs only for WiMAX. In a sequential ξ scheduler control frames, node N_i occupies n_i control frames, which means a total n_i transmits chances, here comes the Equation 2.

$\Phi(rl)$ is transmits chances of control frames which is rl in length. Equation 2 based on an assumption that the control frames was saturated, the transmit chances could be utilized completely.

$$\sum_{t=1}^{K} n_i = \xi\Phi(rl) \tag{2}$$

Suppose ξ series scheduler control frames make the bandwidth request simultaneously, and then the M-DSCH messages transmit through node N_i could be divided into α M-DSCH messages which merely contain the three-way handshake procedure information for WiMAX, β M-DSCH messages which contains the grant, confirm messages for WiFi and WiMAX simultaneously, γ M-DSCH messages which merely contain the three-way handshakes 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 three-way handshake procedure information for WiFi of the total M-DSCH messages in the same nodes, then Equation 3 is conducted.

$$P = \gamma/(\alpha + \beta + \gamma) = \gamma/(n_i + \gamma) \tag{3}$$

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 $n\prime_i$ transmit chances, $n\prime_i$ could be conducted as Equation 4.

$$n\prime_i = n_i/(1 - P) \tag{4}$$

Then the total transmission chances of all nodes in the network environment are as the following Equation 5:

$$\sum_{i=1}^{K} n\prime_i = \sum_{i=1}^{K} n_i/(i - P) = 1/(1 - P) \sum_{i=1}^{K} n_i = 1/(1 - P)\xi\Phi(rl) = \xi\Phi(rl/(1 - P)) \tag{5}$$

In order to meet the total requirement of all the nodes in our 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 τ:

$$\tau = ((1 - r) - (1 - r/(1 - P)))/(1 - r) = r/(1 - r)(1/(1 - P) - 1) \tag{6}$$

Since r is a constant, P and τ 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 designing the scheme.

3 Designing of the Tight Coulping Cooperation System

3.1 DSCH Handshaking Procedure in WiMAX

WiMAX MAC layer is composed by the core disposal WiMAX MAC Module (WMM), Bandwidth Request Queue (RQ), the Availability Queue, and the Grant/Confirm Queue. 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 [3]. 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's 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.

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 [3]. 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

Design of the 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.

- Information Sharing Module: 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. And WiMAX shares Current frame number, Fram start time, Fram duration, Data subframe start time and Minislot length. 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, σ could be computed as the Equation 7.
$$\sigma = floor(l/((1-r)l/256)) = floor(256/(1-r)) \tag{7}$$
- 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.

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.

- 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.

Performance Analysis of the System

The performance analysis of the system is as the Theorem 1.

Theorem 1. *The tightly coupling cooperation scheme of the WiMAX and WiFi draws lossless impacts to the original WiMAX scheme.*

Proof: 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 M-DSCH messages, MSH-DSCH_Request_IE() and MSH-DSCH_Grant_IE() in the M-DSCH contains one or more effective information thus $\alpha+\beta+\gamma = \alpha = \beta$, then $\gamma = 0$ and $P = 0$. Theorem 1 is proved. □

4 Performance Evaluation Through Numerical Simulations

In this section, we evaluated the performance of the proposed scheme through simulations over NS-2. Based on the platform, two typical scenarios are carried out.

4.1 Network Topology and Parameter Settings

Network Topology

In order to analysis the performance of the proposed scheme, two 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 RATs 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 RATs 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.

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 [3]. 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 OFMD_QPSK_1_2 according to [3], data transmission modulation mode is set with the OFDM_16QAM_1_2.

4.2 Simulation Results

Performance Evaluation in Single Hop Scenario

The scenario contains two nodes within each other's signal coverage. Figure 1(a)(b) depicts the average throughput in the single hop scenario, of which the data flow starts at 30s and end at 130s. Solid points in the Figure 1(a)(b) represent the average throughput in the following 10s from time point it correlates. Fig 1(a) shows the WiFi performance comparison between cooperation and noncooperation scheme. When using the DCF mode, the average throughput is 0.77Mbps. 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.

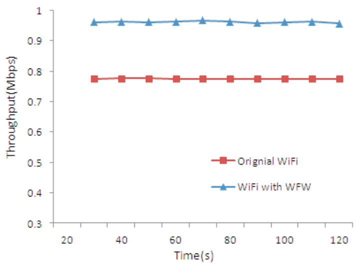
Figure 1(b) shows the WiMAX performance comparison between cooperation and noncooperation scheme. When using the noncooperation scheme, the average throughput of the network is 1.5248Mbps; while using the cooperation scheme, the average throughput of the network is 1.5244Mbps with a deviation of 0.0026%. Hence, the proposed scheme maximizes the throughput and the network efficiency of the WiFi Mesh, assured a nearly lossless WiMAX Mesh network.

Performance Evaluation in the Random Topology

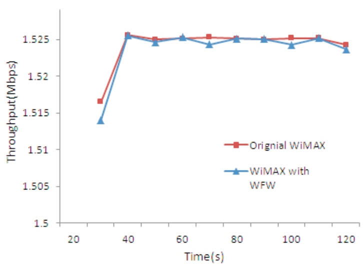
The scenario contains 10 nodes, distributed randomly in a 1000m*1000m area, with 4 CBR flows transmitting simultaneously. Simulation results are showed in the Figure 1(c)(d), the data flow similarly starts at 30s and end at 130s. The solid points in the figure are the same as the points defined in the preceding parts. Figure 1(c) 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)/1.91Mbs*100%=47.6%.

Figure 5(d) 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.

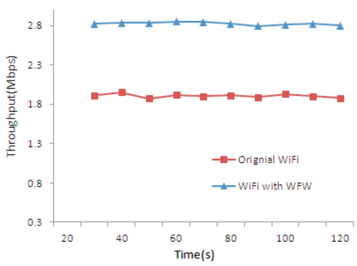
The result of the simulations indicates that the proposed tight coupling cooperation scheme works in accordance with our anticipation that the scheme could guarantee the WiMAX RATs



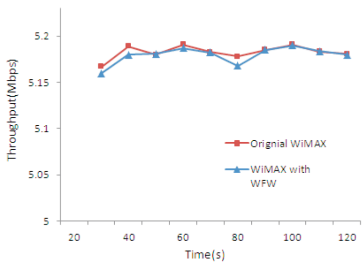
(a) Throughput of WiFi mesh in single hop scenario



(b) Throughput of WiMAX mesh in single hop scenario



(c) Throughput of WiFi mesh in random distributed scenario



(d) Throughput of WiMAX mesh in random distributed scenario

Figure 1: Average throughput in random distributed scenario

with a lossless performance and the WiFi RATs performance with an evident promotion. In our 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 RATs and WiFi RATs. A WFW module is employed to do the bandwidth negotiation for WiFi. A novel M-DSCH was proposed to support the WiMAX to fulfill the bandwidth request-grant-confirm procedure. Numerical results have confirmed that the proposed scheme improve the performance of WiFi, and also draws subtle inference to the original WiMAX performance. Increasing performance of the network assures the QoS of the heterogeneous network.

In the future, we 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.

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