

Radio Resource Management under Fixed-Mobile Convergence Architecture

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Abstract

A strong candidate for the next generation network architecture consists of optical networks, WiMAX mesh networks and WiFi mesh networks. We call it the fixed-mobile convergence architecture. Radio resource management is very important in the shared medium, especially cross the heterogeneous systems. The main focus in this paper is on the channel assignment methods to avoid the problem of co-channel interference and thus achieve higher system throughput. Both centralized and distributed channel assignment approaches are proposed for WiMAX and WiFi mesh networks operated in licensed and license-exempt bands, respectively. Through simulations, WiMAX mesh is shown to achieve 6.67 times improvements in system throughput than WiFi mesh with single channel.

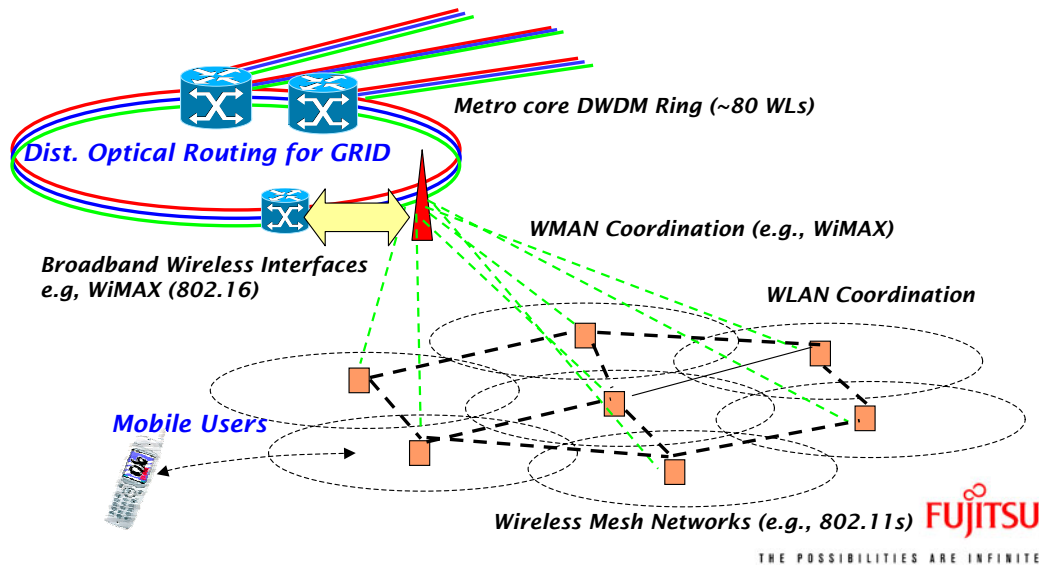
Keywords:

Radio Resource Management, Channel Assignment, optical networks, WiFi, WiMAX, mesh networks



Fixed-Mobile Convergence Architecture

- The architecture for ubiquitous communication includes hierarchies of optical networks, WiMAX, and WiFi mesh



1. Introduction

Recent advancements of communication technology in both optical and wireless networks provide higher transmission capacity and reliability to users and promote fast growth of network usage. The backbones of optical connections realize high speed interconnections while various wireless networks enable ubiquitous broadband communications. The network architecture of next generation networks in our mind incorporates both optical and wireless networks. The concept is called “fixed-mobile convergence” and the main goal is to provide ubiquitous broadband access to users. The hierarchy of the network architecture consists of three levels. At the top level, Wavelength Division Multiplexing (WDM) optical ring forms the core of Metropolitan Area Network (MAN). At the middle level, WiMAX [1] base stations (BSs) form a WiMAX mesh network relaying traffic from lower level to the core network. The WiMAX mesh functions as a wireless MAN and covers a large service region. The bottom level is constituted of the WiFi [2] mesh networks which provide high data rate connections directly to the end users. A transition point between different levels serves as a bridge between two different networks. Traffic is aggregated and disseminated through the transition points. Especially, each optical switch node on the WDM ring, which is a portal node in WiMAX mesh networks as well, converges traffic from wireless networks to wireline networks. Similarly, each WiMAX BS also serves as a portal node in WiFi mesh networks.

The advantages of multi-hops wireless mesh networks are listed below. First, the connectivity range of the core wireline networks is extended. The concept of multi-hops relaying not only extends the communication range of a portal node beyond the single hop coverage but also relaxes the ties of mesh nodes with the infrastructure. Wireline infrastructure is replaced by wireless backhuls in wireless mesh networks. Second, the deployment of mesh nodes can be easier and flexible. The deployment cost is much cheaper than building a wireline connection. Third, the mesh networks are robust since the networks are interconnected by multiple links.



Motivations for Radio Resource Management

- **Wireless radio -- nature of shared medium**
- **Limited available bandwidth**
- **Coexistence of heterogeneous systems (WiMAX, WiFi, bluetooth etc.)**
- **Convergence of heterogeneous systems demands:**
 - Conversion of QoS requirements
 - Resource reservations
 - Fast handover
- **Channel management/assignment within the same system improves system performance**

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1.1 Motivations of Radio Resource Management

There exist many reasons that we need to handle radio resource management under the proposed fixed-mobile convergence architecture. First, because of the nature of the shared medium where wireless radio signal is transmitted through, it is important of controlling radio resource in any wireless systems. Second, the bandwidth of allocated spectrum is limited, improper usage of radio resource results in degraded system performance. Moreover, different wireless systems coexist in the fixed-mobile architecture. They may or may not be operated in the same spectrum. In the case of operating at the same license-exempt spectrum, interferences cross different systems need to be handled. Finally, end-to-end QoS assurance generally cannot be carried over different systems unless a mapping function is well defined between two systems. To achieve end-to-end QoS, not only resource reservations cross different systems but also fast handover are needed.

Radio resource within the same wireless system is important as well. In both WiMAX (IEEE 802.16) and WiFi (IEEE 802.11) systems, multiple channels exist in the allocated spectrum. The past study [3] shows that the IEEE 802.11 mesh networks operated in single channel cannot scale well in the multi-hops environments mainly due to the problem of co-channel interference. The per-node throughput decreases dramatically as the number of nodes in the networks grows. In this paper, our focus is on the channel assignment methods to avoid the problem of co-channel interference and achieve higher system throughput.



WiMax versus WiFi Mesh

| Items | WiMAX | WiFi |
|----------|-----------------------------|----------------|
| PHY | OFDM/OFDMA | OFDM |
| MAC | TDM/TDMA | CSMA/CA |
| Spectrum | Licensed and license-exempt | License-exempt |
| Coverage | ~1 mile | ~100ft |
| Mobility | medium | low |

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2. Comparison of WiMAX Mesh and WiFi Mesh

WiMAX and WiFi mesh systems function in different areas in the fixed-mobile convergence architecture. In this section, we compare the fundamental differences between two systems.

In the physical (PHY) layer, Orthogonal Frequency Division Multiplexing (OFDM) [4] is adopted in IEEE 802.11a/g. OFDM is also one PHY option in 802.16. In addition, Orthogonal Frequency Division Multiple Access (OFDMA) [4] is adopted as one PHY option in IEEE 802.16.

The MAC in WiFi is the contention-based CSMA/CA but the MAC defined in WiMAX is contention-free. The WiMAX base station distributes the resources to WiMAX stations across the time domains. More specifically, in the point-to-multipoint (PMP) MAC operation, Time Division Multiplexing (TDM) and Time Division Multiple Access (TDMA) are adopted in the Up Link (UL) and Down Link (DL), respectively.

The allocated spectrum for WiMAX includes both license-exempt and licensed bands while WiFi system is completely operated in the license-exempt band.

The coverage range of a WiMAX base station is much larger than a WiFi access point. Approximately the non-line-of-sight distance of 1 mile is reachable by a WiMAX base station while a WiFi access point in practice can only reach 100 feet.

Finally, the support of mobility in WiMAX is higher than that of WiFi system due to the larger coverage range. However, the mobility support in WiMAX is still less than 3G systems.



Centralized versus Distributed Channel Assignment

| Items | Centralized | Distributed |
|-------------------|--------------------------------|--------------------------------|
| Advantages | High channel utilization | Robustness |
| | Well controlled resource usage | Simplicity |
| Disadvantages | High control overhead | Low channel utilization |
| | Vulnerability | Less controlled resource usage |
| Suitable Spectrum | Licensed | License-exempt |

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3. Comparison of Centralized and Distributed Channel Assignment Approaches

Proper usage of multi-channels within the same system can improve the overall system performance. Channel assignment within the same system can be executed either at a central controller or at each nodes in a distributed way. In this section, we compare the advantages and disadvantages of both centralized and distributed channel assignment methods. Different strategies of channel assignment are suitable to being applied to licensed and license-exempt spectrum.

In the centralized channel assignment approach, the channels (resource) are allocated by a controller. In order to decide how to allocate the channels, the controller needs to collect the topology and traffic information from the mesh nodes periodically. Then the results of channel assignments need to be disseminated to all mesh nodes for further adjustment. Because the controller has the knowledge of traffic conditions within its control range, the better channel utilization can be achieved in the centralized channel assignment approach. The resource within the control range is also well controlled. The contention-free MAC in IEEE 802.16 is one example of centralized approaches. However, the centralized approach suffers from high overheads of control messages. The region closer to the controller is more congested because the control messages are directed towards or away from the controller. The issue of vulnerability of the controller could be a potential problem for centralized approaches.

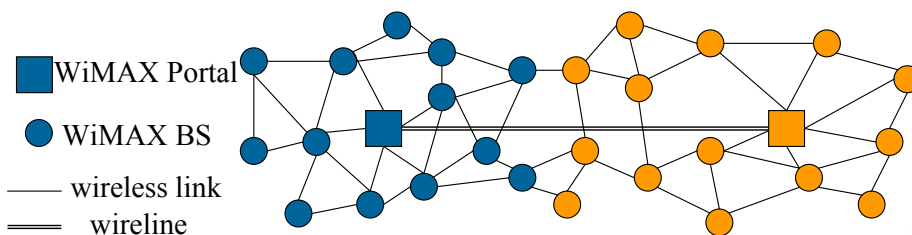
On the other hand, in the distributed approach, each mesh node decides which channels to use based on the local information, including topology, channel conditions and traffic conditions. Distributed approach is simple and robust compared with the centralized approach. Nevertheless, the low channel utilization and less controlled usage of resource degrade the system performance.

Therefore, distributed approach is suited to the license-exempt spectrum because the same band could be used by other systems. Immediate monitoring of variations in channel conditions is more effective than intending to control the resource. For licensed spectrum, the centralized approach is recommended simply because of better performance.



Centralized Channel Assignment in WiMAX Mesh

- WiMAX portal assigns subchannels to wireless links within its cell based on their link loads
- Decision made by a portal is based on:
 - link load collected periodically at the portal
 - interferences **cross** different mesh cell
- A **feasible** centralized approach only endures small overhead



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4. Centralized Channel Assignment in WiMAX Mesh Networks

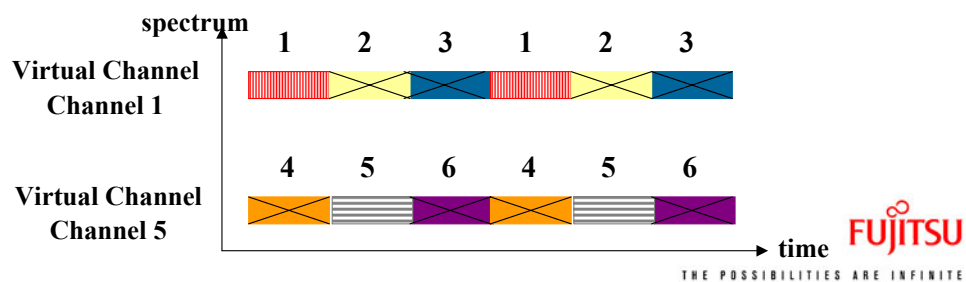
The proposed centralized channel assignment in WiMAX mesh system is executed at the portal node. Periodically each WiMAX base station sends a summary of its traffic load to the portal, including the traffic load of each link. This traffic information could be also incorporated in the routing control packets. Two factors are considered in the channel assignment problem. First, the link carrying higher traffic load is granted more resource (subchannels and slots). Second, to achieve interference-free communications in WiMAX mesh, the interferences from both within the same mesh cell, which represents the region under control of the portal node, and cross different mesh cells are needed to be considered. Once computing the results of channel assignment of its mesh cell, a portal node sends a report to the portal nodes of its adjacent mesh cell.

The proposed centralized channel assignment approach only endures limited amount of control overheads. It is scalable and feasible for a large scale WiMAX mesh system.



Combination of TDM and OFDMA

- **Combination of TDM and OFDMA ideally creates infinite number of virtual channels**
 - Higher flexibility of channel usage results in higher channel utilization
- **Example: if a channel contains 2 orthogonal subchannels and the usage of each subchannel is further divided into 3 TDM slots, then we create 6 virtual channels in a channel**



4.1 Combination of TDM and OFDMA

The centralized channel assignment in WiMAX mesh may require a large number of subchannels to achieve the optimal performance. However, the number of subchannels defined in 802.16 [5] may not be sufficient for flexible channel assignment. Nevertheless, the problem can be easily solved by combining both TDM and OFDMA to create as many virtual channels as required. Because of higher flexibility of channel usage, the higher channel utilization and thus the better system performance is achieved.

We illustrate the concept of combining TDM and OFDMA by a simple example. Suppose there are 2 orthogonal subchannels in a WiMAX channel but the least number of subchannels we need is 6. Then we simply divided the usage of each subchannel into 3 chunks in the time domain to obtain 6 virtual channels in a channel.



Distributed Channel Assignment in WiFi Mesh Networks

- **WLAN is operated in license-exempt spectrum**
 - Interference sources could come from anywhere
 - Any device could not have absolute control of radio resource usage
- **A distributed approach in which each MP assigns the channels to its radios is preferable**
- **The decision is based on the channel condition collected by both active and passive scanning**
 - **Active scanning:** a MP sends out a probe packet and receives a response packet from its neighbor
 - **Passive scanning:** While in idle or NAV states, a MP switches to another channel to overhear the conditions of other channels
- **The channel statistics collected by a MP is broadcast to its one hop neighbors such that every MP can learn the channel conditions in two-hops neighborhood**
- **A MP selects the channels with less usage and interferences**

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5. Distributed Channel Assignment in WiFi Mesh Networks

In this section we present some of ideas of the distributed channel assignments in WiFi mesh networks. Since the WiFi networks are operated in the license-exempt band which is used by many wireless systems, the interferences could come from both within the same system and different systems. It is impossible for a device to guarantee the absolute control of radio resource. Therefore, a distributed approach in which each mesh node determines its channels based on the local information and adjusts to different channel conditions faster is more preferable.

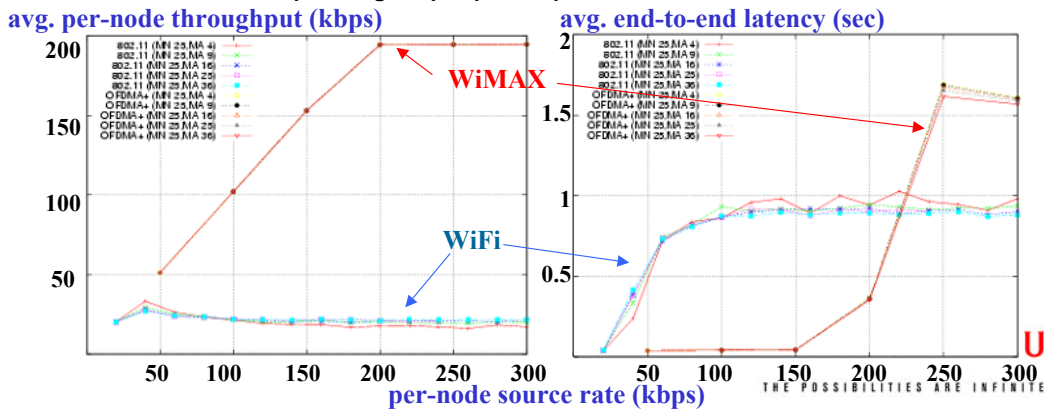
The main information required to decide channel assignment is the channel condition. Each mesh node collects the channel conditions of different channels from both active and passive scanning methods. In the active scanning method, a mesh node sends out a probe packet to search for its one-hop neighbors tuned to the same channel. Upon reception of a probe packet, a neighbor node sends back a probe response packet. Through active scanning, a mesh node knows the number of neighbors operated at the same channels. On the other hand, the passive scanning uses overhearing while in idle or NAV state to collect the statistics of channel usage. Moreover, the channel statistics collected locally can be broadcast to its one-hop neighbors such that a mesh node is aware of the channel conditions in its two-hops neighborhood.

The policy of selecting channels at a node is to simply choose the channels with the least utilization.



Simulation Results of WiMAX Mesh

- Comparison of the performance of WiMAX mesh (TDM+OFDMA) with single channel WiFi Mesh
- Square topology, each mesh area contains 25 mesh nodes
- The same bandwidth of used spectrum = 11 Mb
- For 90% delivery ratio, WiFi and WiMAX mesh achieve 30 and 200 kbps (avg. per node throughput), respectively \Rightarrow 6.67 times improvement
- Reasons of improvements
 - Interference-free setting eliminates the overheads due to collisions
 - Centralized planning fully exploits spatial reuse



6. Simulation Results of WiMAX Mesh Networks

In this section we compare the performance of the centralized channel assignment WiMAX mesh networks with the conventional single channel, single antenna WiFi mesh networks using ns-2 simulator [6] with CMU-wireless extensions [7]. The topology under consideration is the 5*5 square grid where the portal node is located at the center position. The traffic source in our simulation is the constant bit rate (CBR) traffic. Each mesh node has a CBR flow destined to its center portal node and the data rate of CBR flows from all mesh nodes are the same. The bandwidth of the allocated spectrum of the system in terms of the data rate is assumed to be 11Mbps, the same for WiFi and WiMAX mesh for fair comparison.

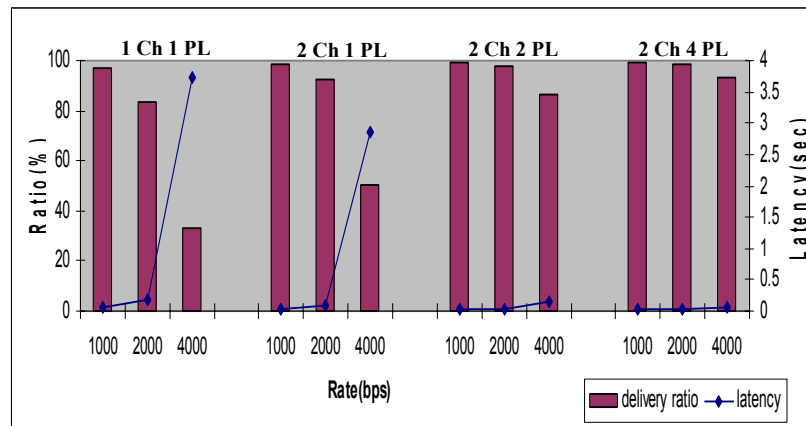
The performance of average per-node throughput and average end-to-end latency are shown in the above two figures. The index in x-axis represents the data rate of a constant bit rate flow from each mesh node. We increase the data rate until the network is saturated. The maximum per-node data rate can be supported to achieve 90% delivery ratio are approximate 30 and 200 kbps for WiFi and WiMAX mesh networks, respectively. We have the improvement of 6.67 times in per-node throughput. The performance of latency in WiMAX mesh networks is also much better than the WiFi mesh networks under the non-saturation condition.

The reasons for the significant improvements come from two aspects. First, the interference-free channel assignment in WiMAX mesh networks eliminates the overheads (including dropped data packets) due to collisions. Second, the centralized planning fully exploits spatial reuse and has higher channel utilization.



Preliminary Simulation Results of WiFi Mesh Networks

- 8*4 MPs in grid structure, 100 static STAs
- Each STA starts one CBR (4kbps) flow. 50% of the destinations locate outside mesh
- BW = 11 Mbps, 12 MPs interfere with the central portal



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7. Preliminary Simulation Results of WiFi Mesh Networks

In this set of simulation we try to understand the detailed performance of WiFi mesh networks. The simulation scenario includes 8*4 mesh access points (APs) in the rectangular grid structure. 100 stations locate randomly in the field. Each station starts a CBR connection with 50% probability of selecting the destination outside the mesh area, and the other 50% probability that a destination locates at the same mesh area. The bandwidth in the simulation is still 11 Mbps. In the case where the single portal located at the center of grid, the portal encounters 12 neighboring mesh nodes would cause the interference.

Four cases are simulated and shown from left to right. The first case is the result of using single channel and single portal node. That is, all the nodes, including both mesh APs and stations are operated at the same channel. In the second case, two channels are used for the mesh AP to stations and mesh AP to mesh AP communications, respectively. In the third and fourth case, we increase the number of portal nodes to be 2 and 4, respectively.

Due to high congestion around the region close to portal nodes, the system performance is constrained by the throughput of portal nodes. It is shown that with additional channel or portal nodes, the performance of WiFi mesh networks is much improved.



Conclusion and Future Work

- **Radio resource management is important for the next generation fixed-mobile convergence networks**
- **Centralized channel management operated in licensed spectrum is preferable to WiMAX mesh**
- **Distributed channel management operated in license-exempt spectrum is preferable to WiFi mesh**
- **The study of radio resource management across WiMAX and WiFi mesh systems is under investigation**

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8. Conclusion and Future Work

The radio resource management is extremely important for the next generation of fixed-mobile convergence networks, consisting of optical, WiMAX mesh and WiFi mesh networks. In this paper, we focus on the channel assignment problem in both WiMAX and WiFi mesh networks. Both centralized and distributed channel assignment approaches are proposed for WiMAX and WiFi mesh networks operated in licensed and license-exempt bands, respectively. Through simulations, WiMAX mesh is shown to achieve 6.67 times improvements in system throughput than WiFi mesh with single channel.

In the future, we would like to further exploit the radio resource management across WiMAX and WiFi mesh systems.

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