Integration of IEEE 802.11 WLANs with IEEE 802.16 based multihop infrastructure mesh relay networks:

A game theoretic approach to radio resource management

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Outline

- Introduction
- Overview of IEEE 802.16/WiMAX
- The Integrated WiMAX/WLAN Network
- Research Issues in an Integrated WiMAX/WLAN Network
- Proposed Game-Theoretic Model
- Performance Evaluation
- Conclusions
Introduction

- IEEE 802.16 is a promising solution to provide backhaul support for WLAN hotspots
- An integrated 802.16/802.11 network can be used to extend the service availability for mobile Internet applications
- Although, PHY and MAC layer are specified in 802.16 standard, radio resource management remains an open issues

- Resource management and admission control of 802.16 and 802.11 should be considered jointly to achieve
  - High network utilization
  - High level of QoS
Overview of IEEE 802.16/WiMAX

- Physical Layer
  - Different specifications for different air interface for different frequency band
    - WirelessMAN-SC
    - WirelessMAN-SCa
    - WirelessMAN-OFDM
    - WirelessMAN-OFDMA
  - Adaptive Modulation and Coding (AMC)

- MAC layer
  - Connection-oriented MAC protocol

- Mesh operation
  - Mobile Multi-Hop Relay (MMR) is also suitable as a wireless backhaul to serve WLAN hotspots
The Integrated WiMAX/WLAN Network
Edge Router with Two Air Interfaces

- Two types of traffic
  - Local traffic
    - Connection in the coverage area of WLAN
  - Relay traffic
    - Connections traversing the wireless backbone to an Internet gateway

- Protocol adaptation
  - Interworking between 802.11 and 802.16
Research Issues

• Topology Management
  – Mesh/Relay topology can provide wireless backhaul links in a lower cost

• Radio Resource Management (RRM)
  – Efficient RRM at mesh router can be achieved by intelligent bandwidth allocation, channel assignment, and admission control
  – Fairness between local and relay traffic and prioritization among different types of traffic must be considered
  – [7] [8] was presented to solve RRM and transmission problem
  – Cognitive Radio (CR) was proposed in [9] for sharing radio resource in frequency, space, and time domain
  – Power control should be also considered to minimize transmit power for avoiding interference
Research Issues

- Link-Level Error Control and End-to-End QoS
  - Space diversity technology [11] can improve the transmission performances
    - Relying on transmissions by several nodes with each node acting as a virtual transmission antenna for the receiver
    - Integration of error control and error recovery as well as packet scheduling and routing schemes are interesting research issues

- Routing Strategies
  - Metrics proposed in [12] should be taken into account
    - Expected transmission count (ETX)
    - Per-hop round-trip time (RTT)
    - Per-hop packet pair delay
  - A crosslayer optimization approach should be used
    - Routing protocol performance depends on the resource allocation scheme used at each BS
Research Issues

• Protocol Adaptation and QoS Support
  – Heterogeneous network integration are discussed for years
  – The approaches to QoS provisioning are different in 802.16 and 802.11 standard
  – A unified QoS framework based on QoS mapping was proposed in [15]
  – However, the mechanisms to ensure the QoS requirements were not considered

• Optimizing Transport Layer Protocol Performance in an integrated WiMAX/WLAN network
  – Multihop transmission affects the error recovery and congestion control performance
  – There exists an optimal TCP windows size to achieve the highest throughout [16]
    • Only a single TCP flow was considered
Research Issues

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<tr>
<td>Channel allocation</td>
<td>Topology management [5]</td>
<td>Dynamic channel allocation in 802.16/802.11 [8]</td>
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# Key Contributions of Related Work

<table>
<thead>
<tr>
<th>Components</th>
<th>Key contribution</th>
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<tr>
<td>QoS architecture [15]</td>
<td>An architecture to provide end-to-end QoS in an integrated 802.16/802.11 network</td>
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<td>Mobile hotspot [1]</td>
<td>An architecture for two-hop communication for mobile hotspot based on UMTS</td>
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<td>Evaluation of link-quality metrics [12, 13]</td>
<td>Detailed evaluation of link-quality metrics used in multihop routing interference-aware routing and scheduling for 802.16 mesh networks</td>
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<td>Congestion-based routing [14]</td>
<td>Congestion-based routing in multihop TDD-CDMA network to minimize the overall transmission power and a new dynamic channel allocation algorithm</td>
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<td>End-to-end performance [10]</td>
<td>Analytical model to obtain end-to-end delay performance for multihop relay network</td>
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<td>Topology management [6]</td>
<td>Optimization formulation to obtain the topology for an 802.16 backhaul network</td>
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<td>Cognitive radio [9]</td>
<td>Cognitive radio approach for dynamic spectrum allocation, power control, and time agility for an integrated 802.16/802.11 network</td>
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<td>Load balancing and sharing [8]</td>
<td>Load balancing and sharing scheme based on channel assignment to avoid interference</td>
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<tr>
<td>Cooperative diversity [11]</td>
<td>New transmission method based on cooperation of the multiples node in different locations to improve diversity gain</td>
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Bandwidth Management and Admission Control – A Game Theoretic Model

• A game is described by a set of rational players, the strategies associated, and the payoffs

• BSs *bargain* with each other so that maximum benefit by playing the game without cooperation
Proposed Architecture for Integrating IEEE 802.11 and 802.16
Bargaining Game Formulation

• Player:
  – The traffic from WLAN, standalone SS, and relay traffic

• Strategy:
  – Total burst size in a transmission frame

• Payoff:
  – Total utilization gained from the achievable transmission rate
Proposed Game-Theoretic Model

• The bargaining game model for distribute bandwidth management and admission control is proposed in an integrated WiMAX/WLAN multihop network.

• Using bargain game for bandwidth allocation is fair and efficient.
  – Pareto Optimality can be achieved [20]
    • The resource allocated can not be further utilized by increasing or decrease some resource hold by someone.
Pareto Optimality and Equilibrium of Bandwidth Sharing at BS-1
Proposed Game-Theoretic Model

• Utilization function of network model [19]
  \[ U(T) = w \log(1 + \alpha T) \]

• Since different types \((j)\) of connections \((i)\) have different preferences on bandwidth allocation, the equation modified as:
  \[ U_j^{(h)}(B_j) = \sum_{i \in C_j} w_i \log \left(1 + \alpha_i T_i^{(h)} \left( D_i^{(h)} \right) \right) \]

• Upon receiving bandwidth request, BS performs bandwidth estimation based on estimated successful packet transmission and packet collision probabilities to get “Transmission Rate” (denoted as \(T\)) for admission control
Proposed Game-Theoretic Model

• Because three types of traffic have different behavior, the allocated block sized should be weighted
  – The amount of bandwidth assigned to connection $i$ of type $j$ at BS $h$ is determined based on weight $w_i$

\[
D_i^{(h)} = \frac{w_i B_j}{\sum_{i \in C_j} w_i},
\]

where $D_i^{(h)}$ is the burst size for connection $i$, $B_j$ is the total burst size allocated to connections of type $j$, and $\sum_{i \in C_i} w_i$ is the sum of weights of connections of type $j$. 
Bandwidth adaptation under different number of ongoing connections

- WLAN and relay traffics are given higher priorities
- Equilibrium is stable in which bandwidth adaptation function are linear
Average number of ongoing connections under varying connection arrival rate

- Average number of ongoing connections increase as traffic intensity increases
Connection blocking probability under varying connection arrival rate

- High blocking Prob. due to bottleneck at BS-1
- Low blocking Prob. due to high priority
Average amount of allocated bandwidth under varying connection arrival rate

- Bandwidth assigned to a connection decreases as traffic intensity increases
Variation in total utilization under varying connection arrival rate

- Total utility increase when connection arrival rate increases

- Total utility do not decrease
  - Incoming connection is reject if admission of the connection reduce total utility
Conclusions

• An architecture for integrating WiMAX and WLAN is presented

• Related issues are overviewed and some solutions proposed have been reviewed

• This study also presents a game-theoretic framework for radio resource management

• A bandwidth allocation scheme has been presented for fair resource allocation and an admission control policy has been proposed to maximize the utilities for different type of connections