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

A game theoretic approach to radio resource management

IEEE Network Magazine, May-June. 2007
Volume 21, Issue 3

林咨銘

2007/10/24

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

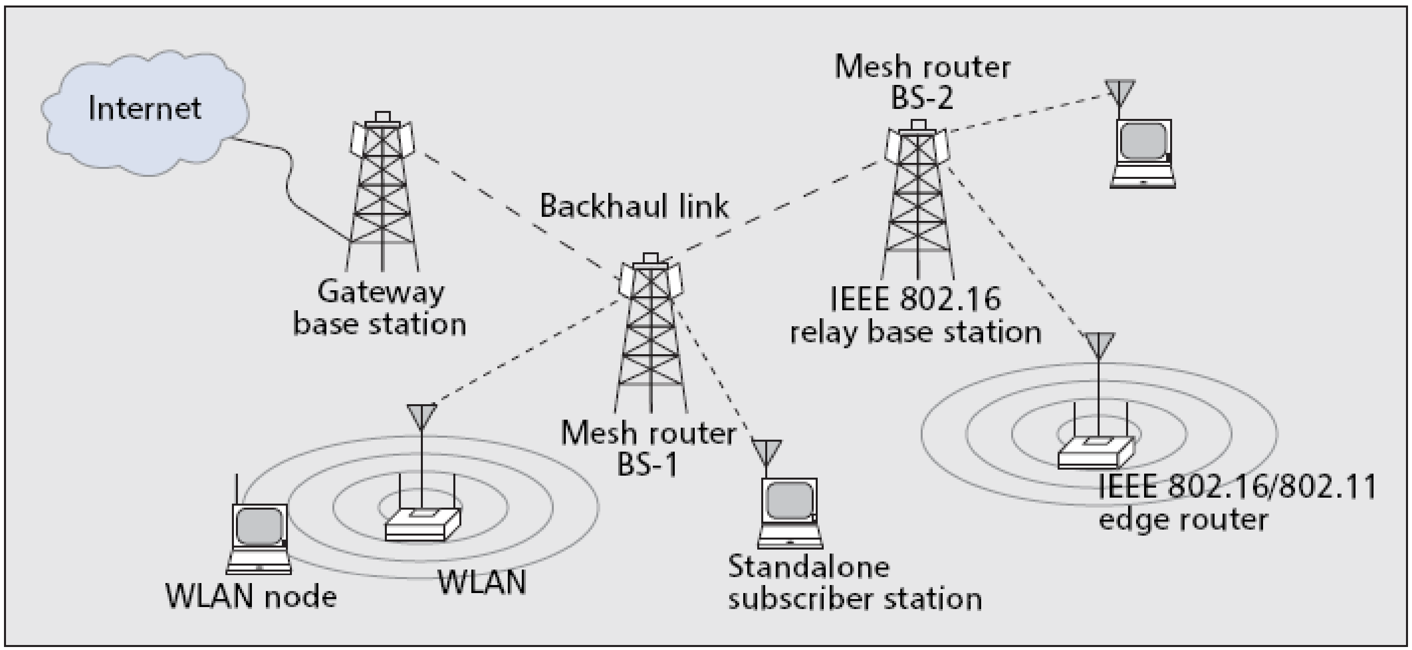
Overview of IEEE 802.16/WiMAX

- 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)

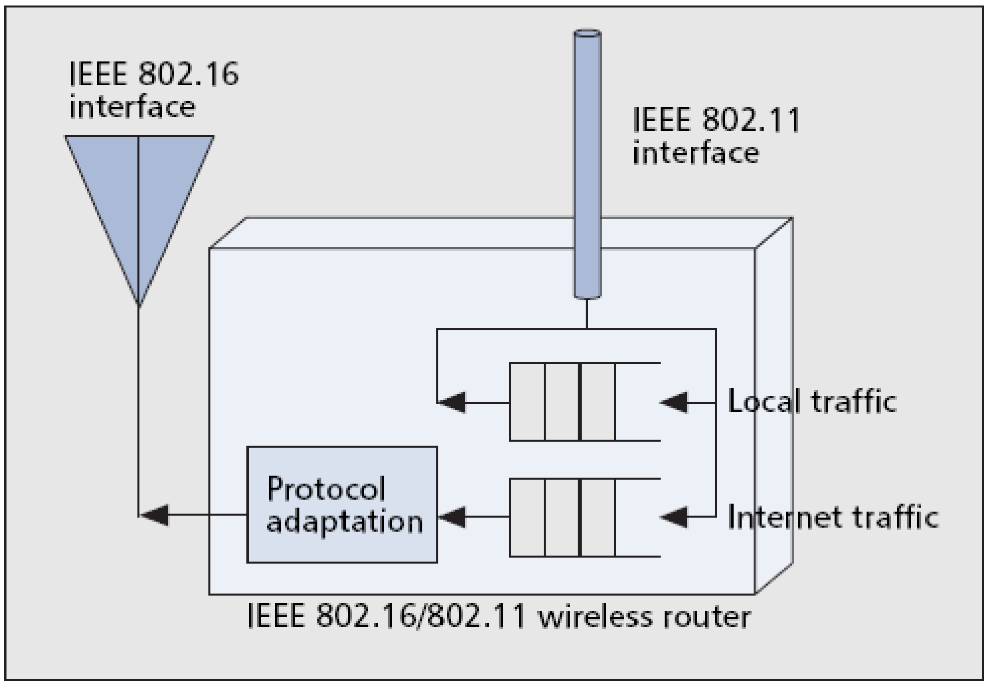
- MAC layer
  - Connection-oriented MAC protocol

- 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

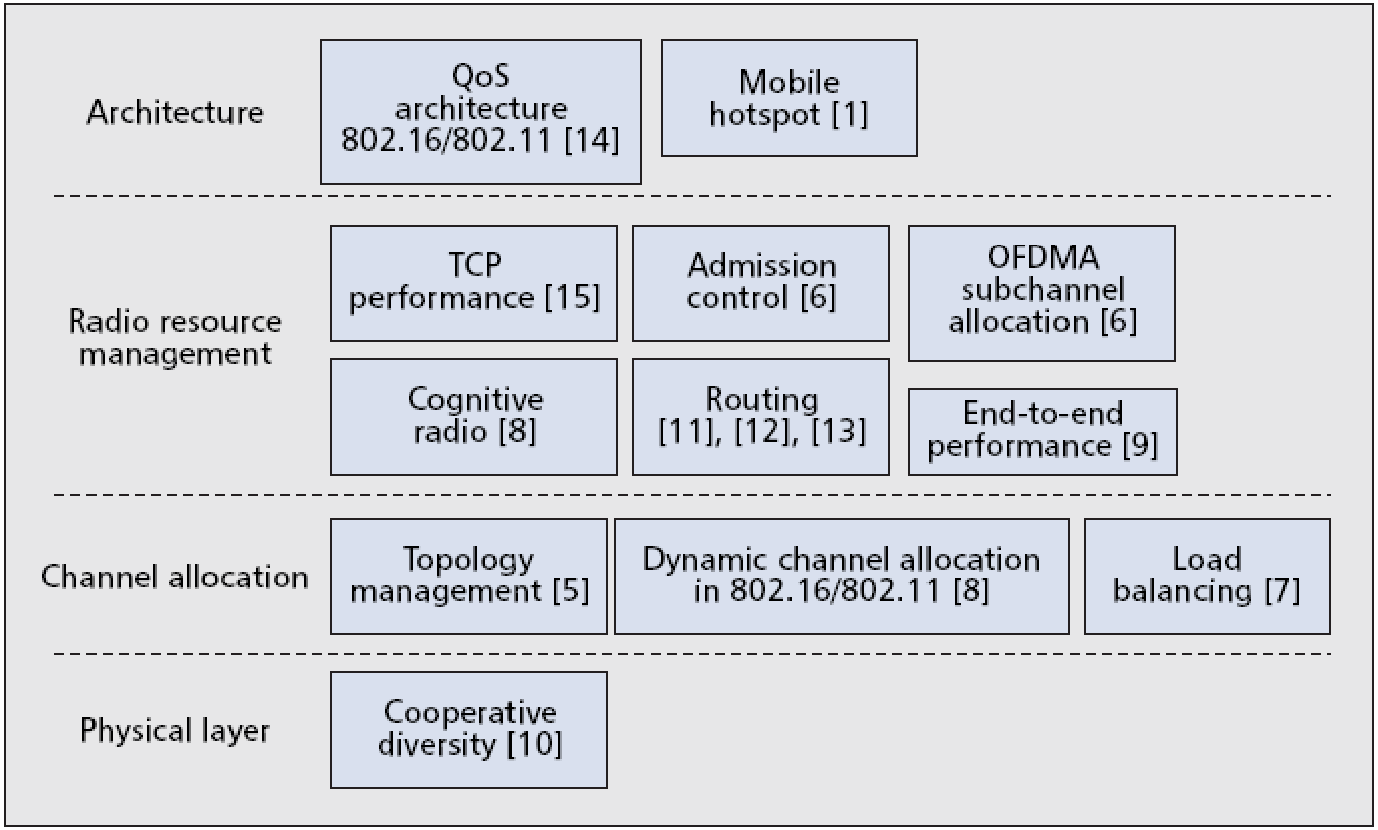
Research Issues

- 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 acing 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



Key Contributions of Related Work

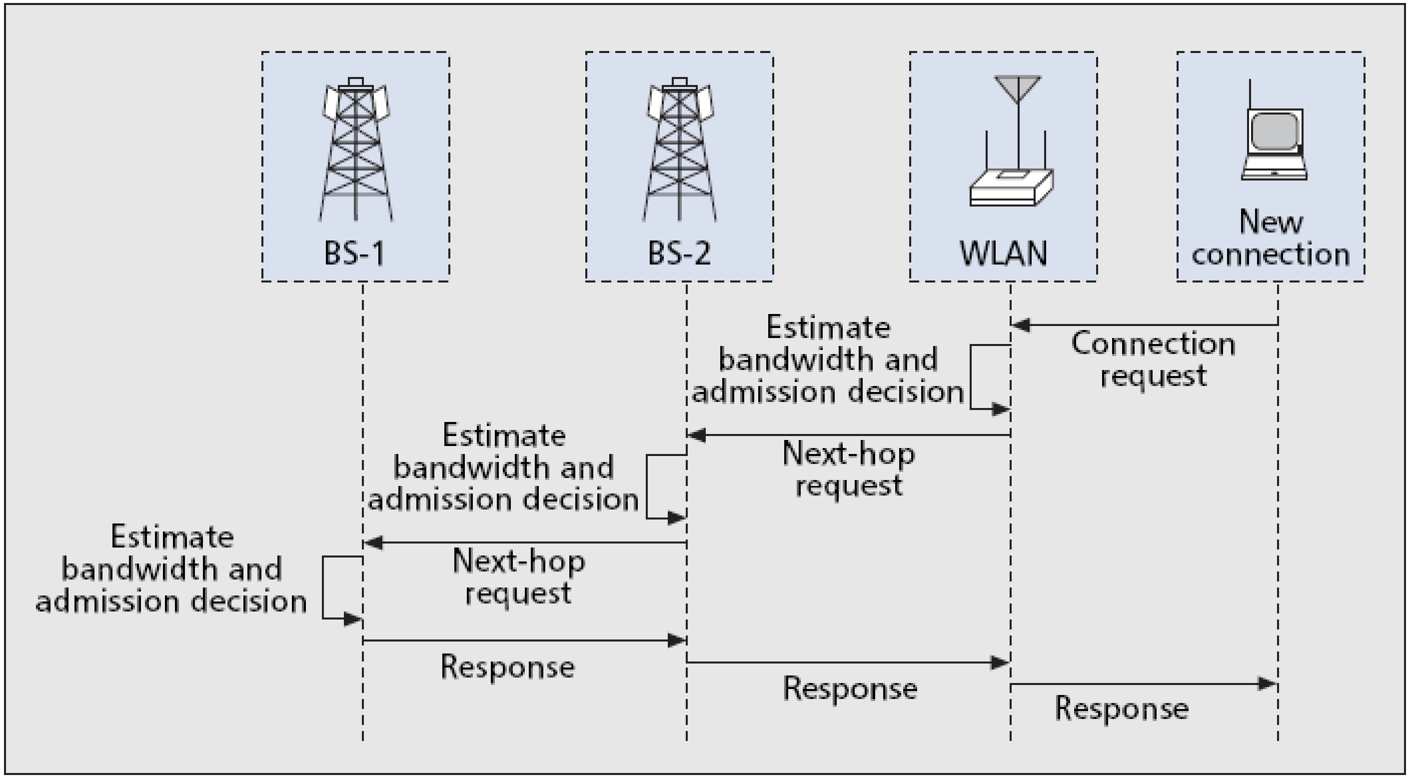
Components	Key contribution
QoS architecture [15]	An architecture to provide end-to-end QoS in an integrated 802.16/802.11 network
Mobile hotspot [1]	An architecture for two-hop communication for mobile hotspot based on UMTS
Resource allocation for OFDMA [7]	Subchannel allocation, route selection, and admission control algorithm for OFDMA-based multihop wireless networks
Evaluation of link-quality metrics [12, 13]	Detailed evaluation of link-quality metrics used in multihop routing interference-aware routing interference-aware routing and scheduling for 802.16 mesh networks
Congestion-based routing [14]	Congestion-based routing in multihop TDD-CDMA network to minimize the overall transmis-sion power and a new dynamic channel allocation algorithm
End-to-end performance [10]	Analytical model to obtain end-to-end delay performance for multihop relay network
Topology management [6]	Optimization formulation to obtain the topology for an 802.16 backhaul network
Cognitive radio [9]	Cognitive radio approach for dynamic spectrum allocation, power control, and time agility for an integrated 802.16/802.11 network
Load balancing and sharing [8]	Load balancing and sharing scheme based on channel assignment to avoid interference
Cooperative diversity [11]	New transmission method based on cooperation of the multiples node in different locations to improve diversity gain

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

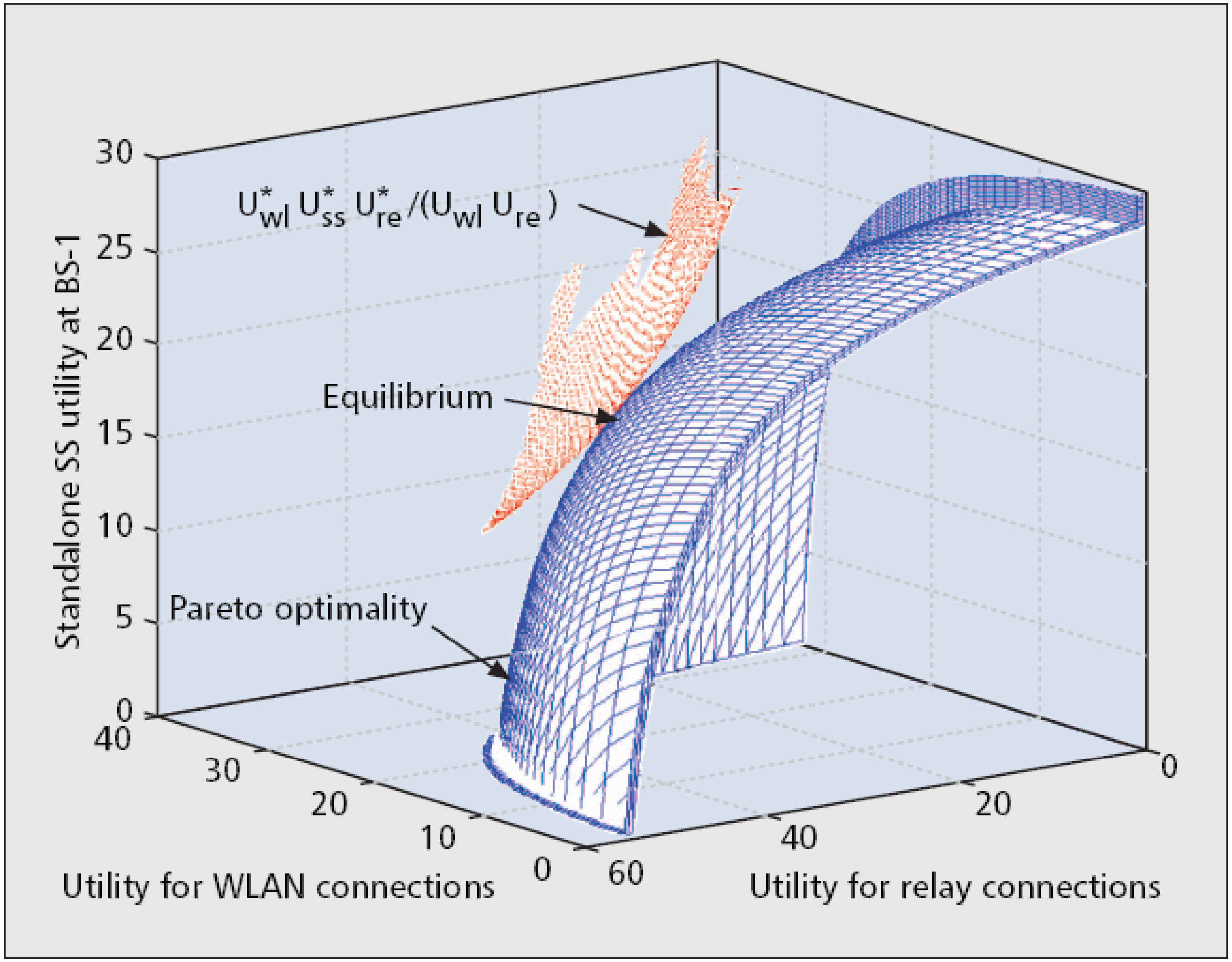
- Player:
  - The traffic from WLAN, standalone SS, and relay traffic
- Strategy:
  - Total burst size in a transmission frame
- Payoff:
  - Total utilization gained from the achievable transmission rate

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 $\underline{T}$) for admission control

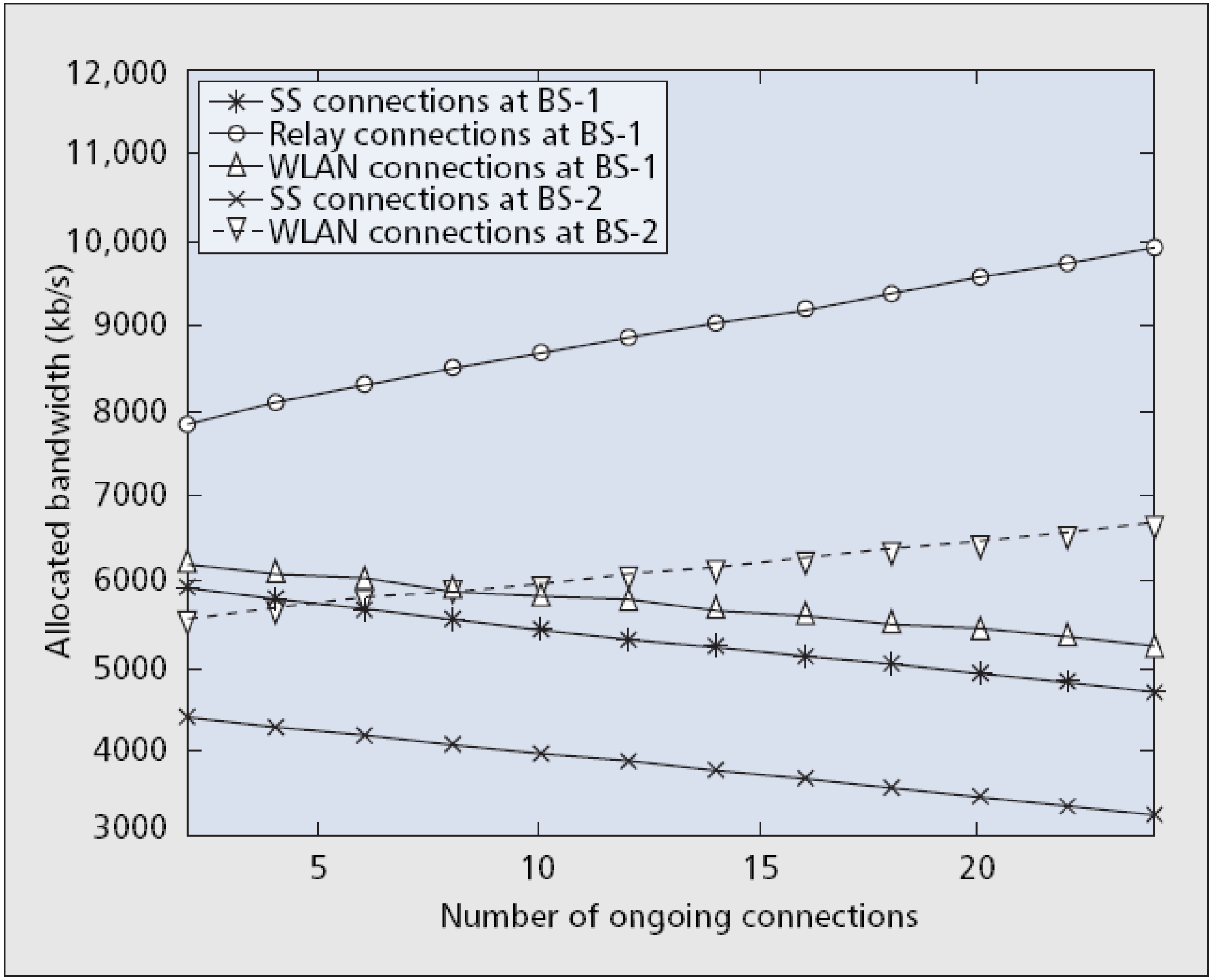
Proposed Game-Theoretic Model

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

$$D_i^{(h)} = \frac{w_i B_j}{\Sigma_{i \in \mathbb{C}_j} w_i},$$

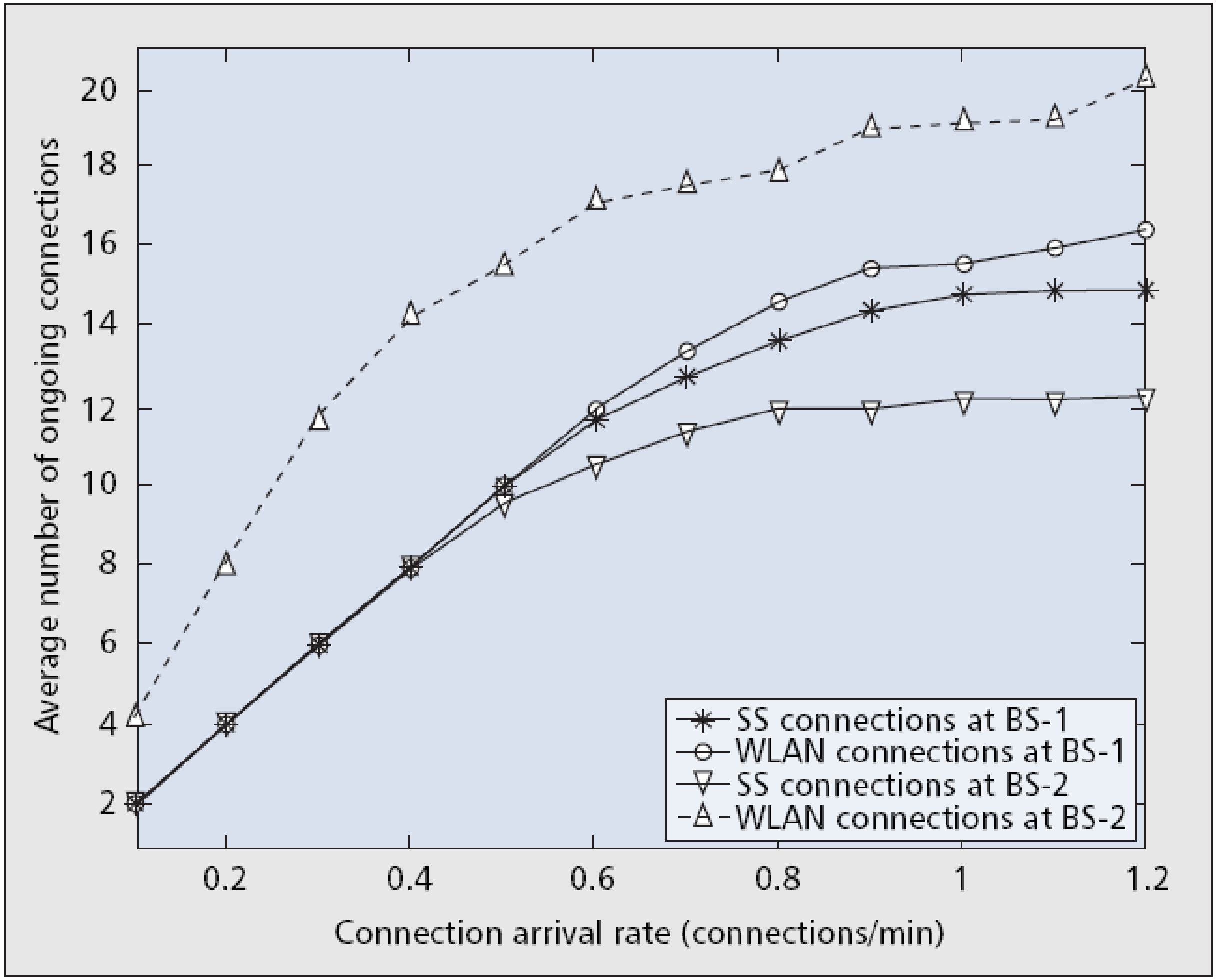
where $D_i^{(h)}$ is the burst size for connection i, B_j is the total burst size allocated to connections of type j, and $\Sigma_{i \in \mathbb{C}_j} w_i$ is the sum of weights of connections of type j.

Bandwidth adaptation under different number of ongoing connections



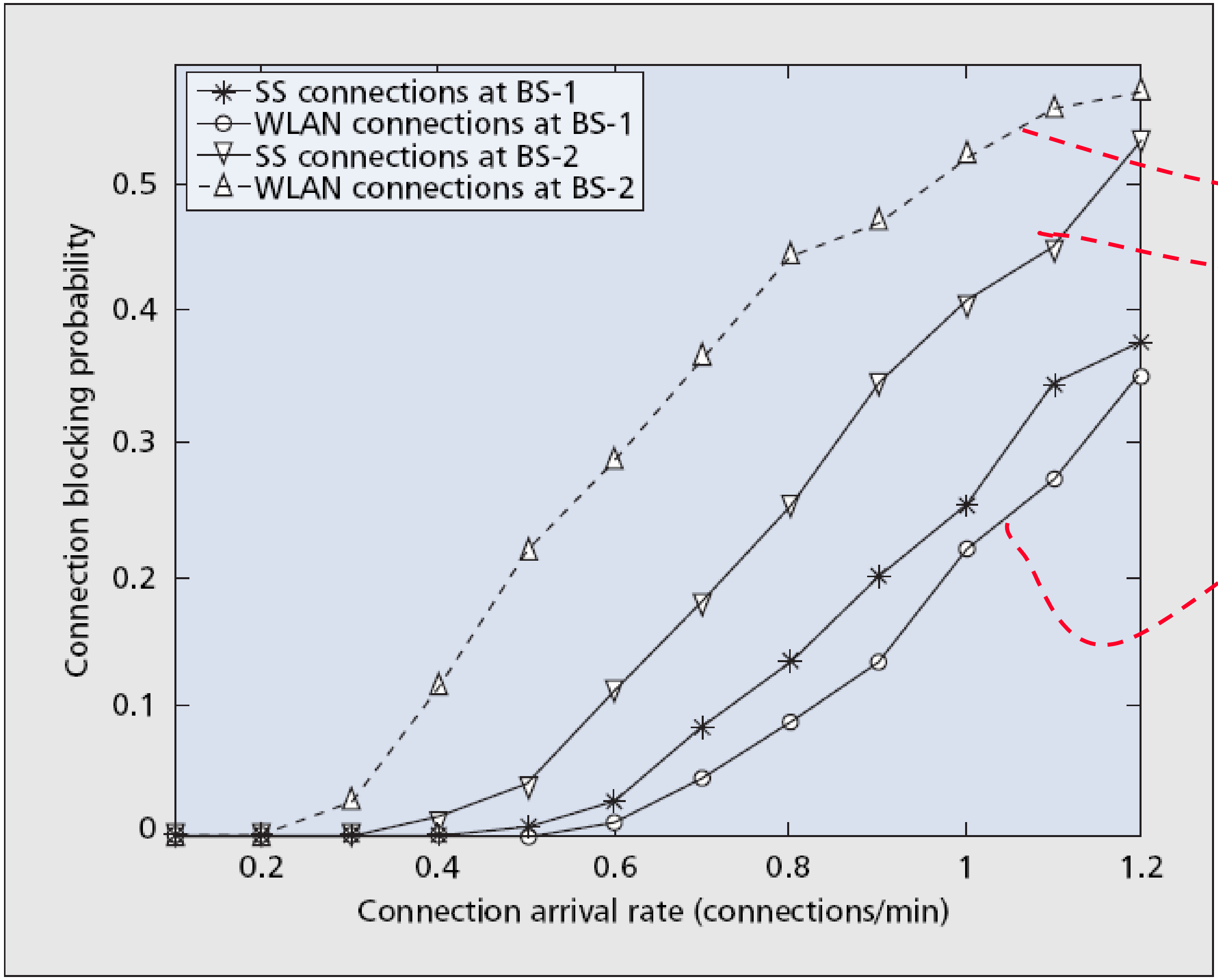
- WLAN and relay traffics are given higher priorities
- Equilibrium is stable in which bandwidth adaptation function are linear

Average number of ongoing connections under varying connection arrival rate



- Average number of ongoing connections increase as traffic intensity increases

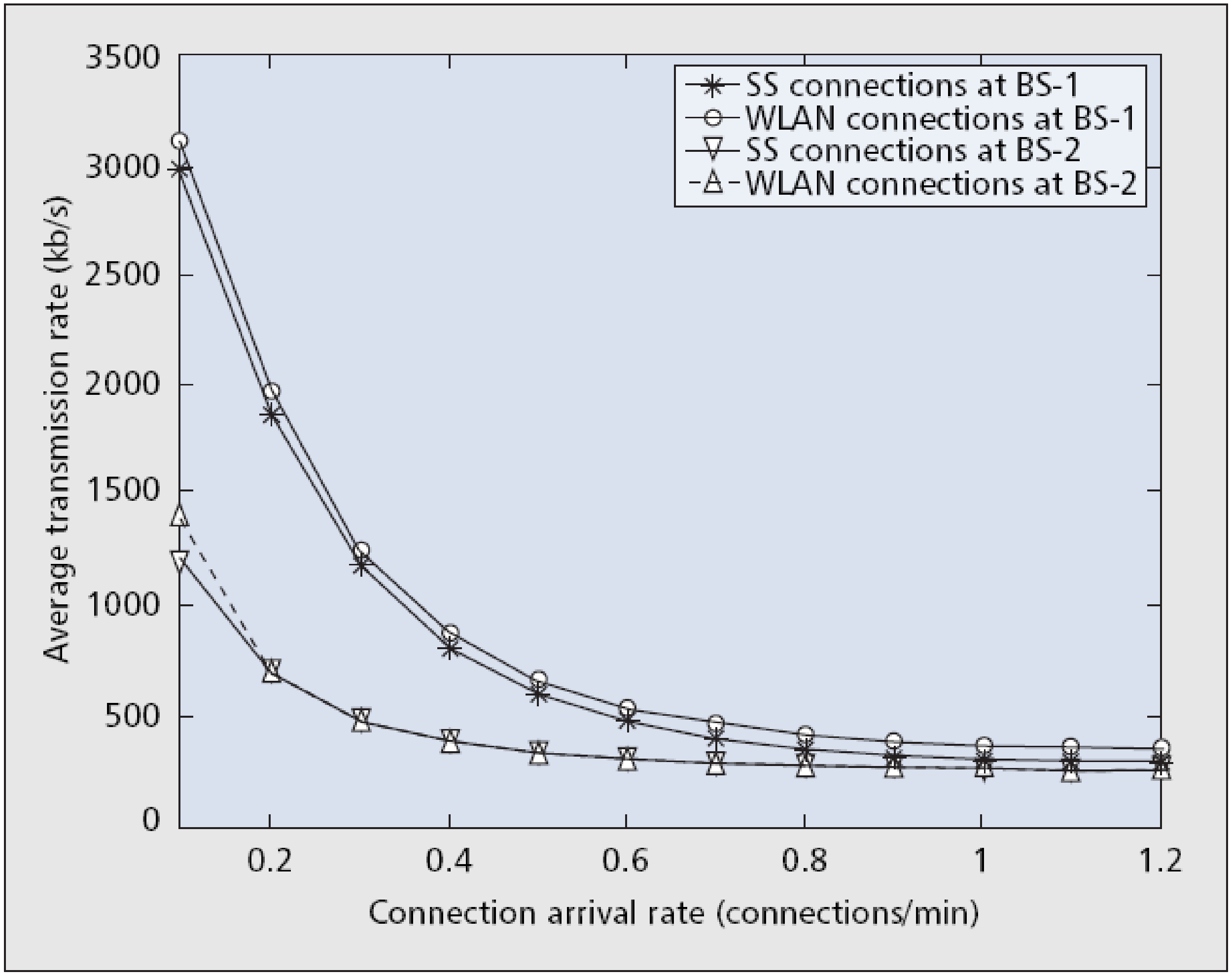
Connection blocking probability under varying connection arrival rate



High blocking Prob. due to bottleneck at BS-1

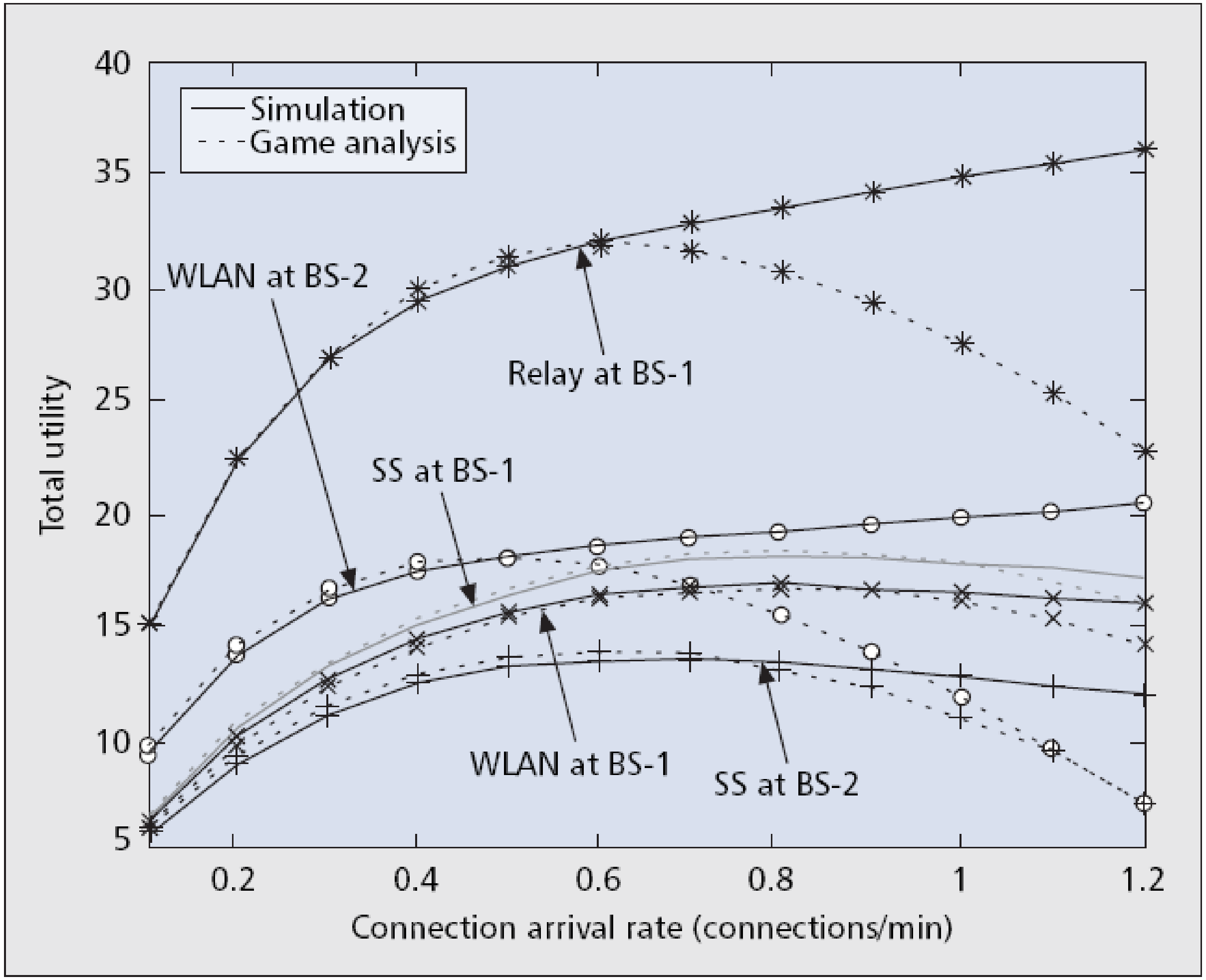
Low blocking Prob. due to high priority

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