IEEE 802 Tutorial:

802.16 Mobile Multihop Relay

Monday 6 March 2006, 18:30 – 20:00

Hyatt Regency Denver at Colorado Convention Center

Centennial D

IEEE 802 Tutorial:

802.16 Mobile Multihop Relay

- **Opening Remarks**

- **General Overview**

- **Economic Feasibility and Serviceability**

- **Technical Study & Feasibility**

IEEE 802 Tutorial:

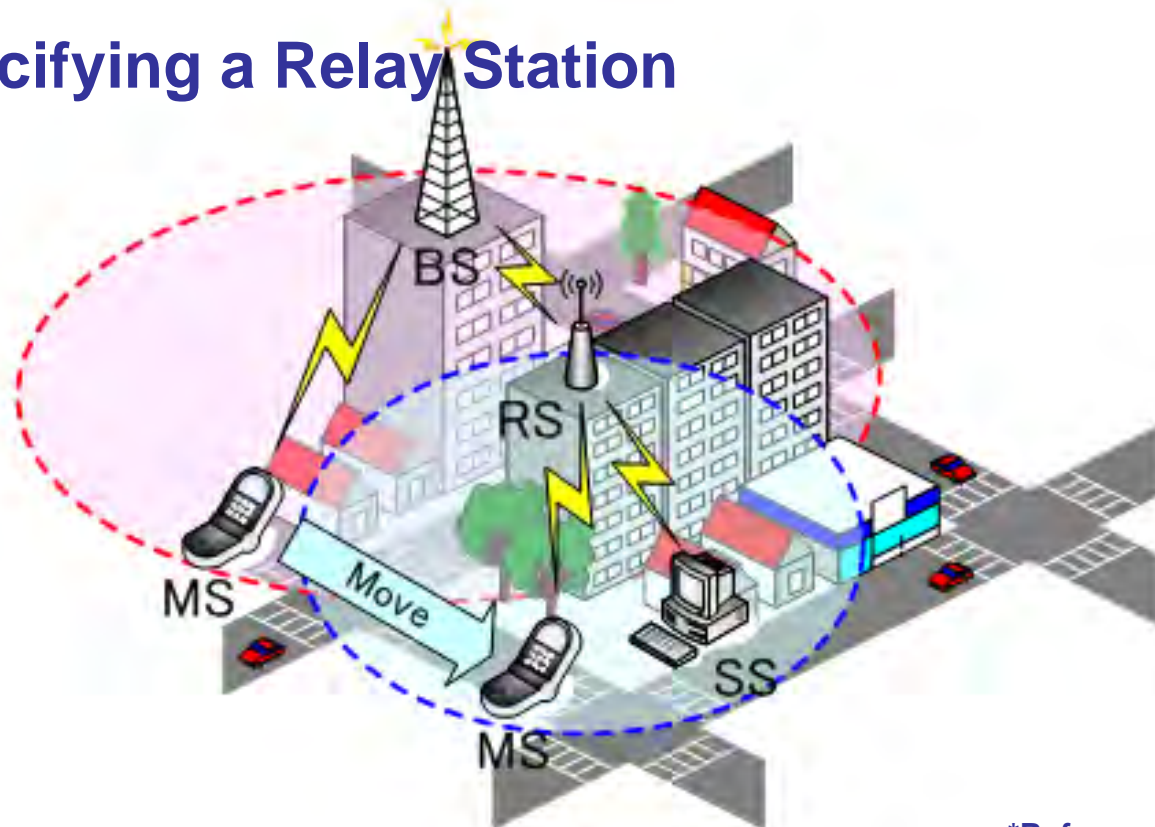## *802.16 Mobile Multihop Relay*
- Opening Remarks -

Roger B. Marks
Chair, IEEE 802.16 Working Group

MMR SG Overview

Aiming to enhance IEEE 802.16 (including 802.16e), to gain:

- ➤ **Coverage Extension**

- ➤ **Throughput Enhancement**

by specifying a Relay Station

MMR-SG History

- May 2005   1st Ad-hoc Meeting on Mobile Multihop Relay (MMR)

- July 2005   2nd Ad-hoc Meeting on MMR

  WG/EC Approval to set up the new SG on MMR

- Sept. 2005   1st SG Session, 16 Contributions

- Nov. 2005   2nd SG Session, 23 Contributions

- Jan. 2006   3rd SG Session, 15 Contributions

- Draft PAR & 5 Criteria forwarded by SG and WG

- Mar. 2006   - This Tutorial and EC Review

- May 2006   1st TG Session, if approved

Purpose of Proposed Project

(from proposed PAR 802.16j)
This amendment provides specifications for mobile multihop relay features, functions and interoperable relay stations to enhance coverage, throughput and system capacity of 802.16 networks.

- PAR and 5 Criteria Related Discussions to follow -

Tutorial Agenda

1. **Opening Remarks**   **Roger B. Marks**

2. **General Overview**   **Mitsuo Nohara**

3. **Economical Feasibility and Serviceability**

                                       Jose Puthenkulam

4. **Technical Study and Feasibility**   **Mike Hart**

Please Enjoy!

IEEE 802 Tutorial:

802.16 Mobile Multihop Relay
- General Overview -

Speaker: Mitsuo Nohara (mi-nohara@kddi.com)
Chair, IEEE 802.16 WG Study Group on Mobile Multihop Relay

Contributors:
M. Asa, JaeWeon Cho, R. Peterson, S. Ramachandran,
K. Saito, A. Sharon, JungJe Son and Rakesh Taori

Contributions

IEEE 802.16 WG MMR SG Volunteers (in random order)

Kenji Saito
I-Kang Fu
Roger Peterson
John Humbert
Vladimir Yanover
Roger Marks

JaeWeon Cho
Wen Tong
Shyamal Ramachandran
Puneet Jain
Mike Hart
Mitsuo Nohara

JungJe Son
Masahito Asa
Ariel Sharon
Jose Puthenkulam
Rakesh Taori

Acknowledgment to: (in random order)

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Nat Natarajan
Hyunjeong Hannah Lee
A. Tang
Ozgur Oyman
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Kerstin Johnsson
K. Singh
Wendy Wong
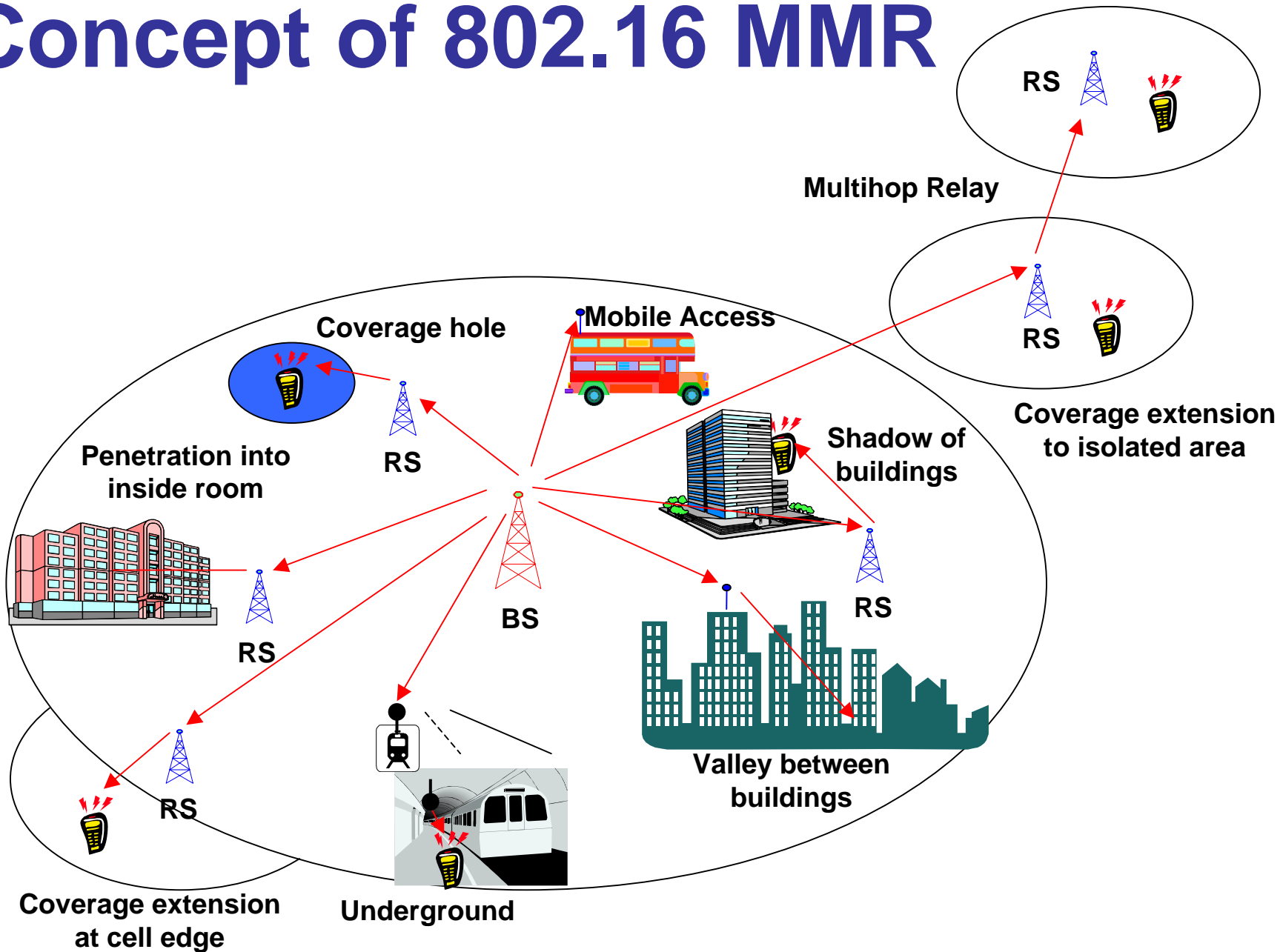**Wern-Ho Sheen**
Chun-Chieh Tseng

Contents

- **Outline of 802.16 MMR**

    - with PAR and Five Criteria

- **Distinctions from the others**

- **Study Topics and Schedule**

    - **MMR Study Topics**

    - **Tentative Schedule**

- **Summary**

Relay Project Overview

- **Aiming at Developing Relay mode based on IEEE802.16e,**
- **To gain:**
  - ➤ **Coverage Extension, and**
  - ➤ **Throughput Enhancement,**
- **by introducing the Relay Stations.**

Concept of 802.16 MMR

Multihop Relay

Coverage extension to isolated area

Coverage hole

Mobile Access

Penetration into inside room

Shadow of buildings

RS

BS

RS

RS

Valley between buildings

Coverage extension at cell edge

Underground

PAR and 5 Criteria
Purpose of Proposed Project

(from draft 802.16j PAR)
This amendment provides specifications for mobile multihop relay features, functions and interoperable relay stations to enhance coverage, throughput and system capacity of 802.16 networks.

PAR and 5 Criteria
Scope of Proposed Project

(from draft PAR 802.16j)

This document specifies OFDMA PHY and MAC enhancement to IEEE Std. 802.16 for licensed bands to enable the operation of relay stations.

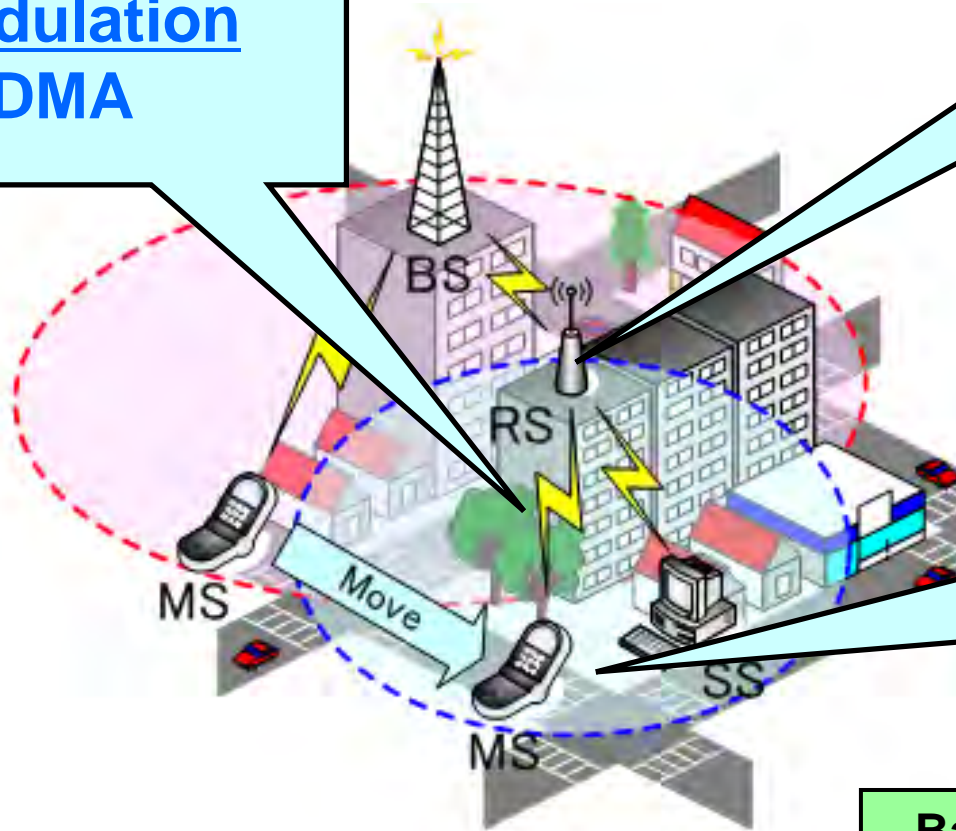***Subscriber station specifications are not changed.***

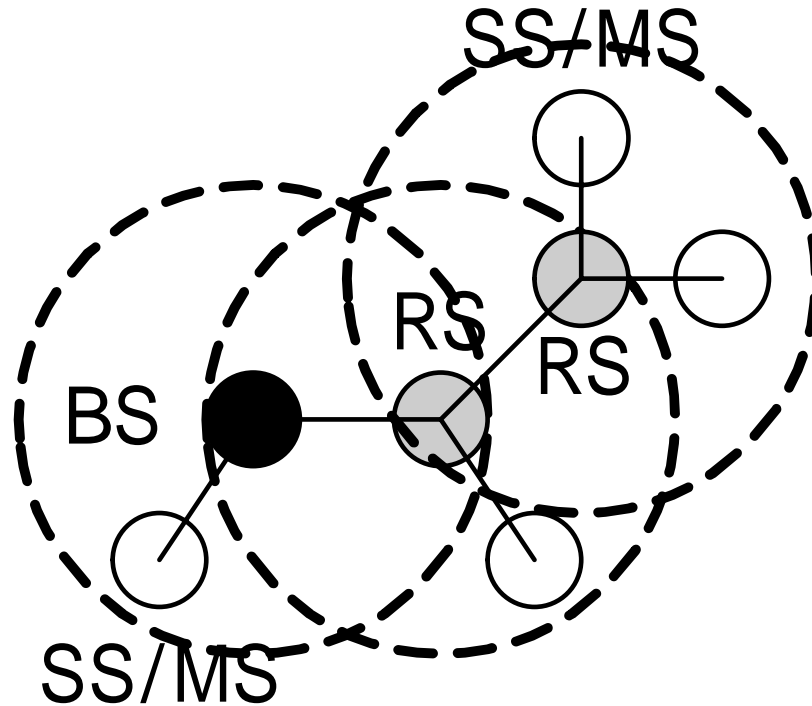# Key Points from the PAR

**Modulation
OFDMA**

**RS Type
Fixed / nomadic /
mobile**

**Terminal
Conventional
802.16 MS/SS**

Backward compatibility kept

BS

RS

MS

Move

SS

MS

Tree Structures for Relay, not Mesh
PMP-based Network Topology for Relay

Requirements:

- **PMP mode compatible**

- **16e mobile station (MS) Support**

<- Those are not supported by current 16-mesh thus require new spec.

Definitions

- **mobile multihop relay (MMR):**
  The system function that enables mobile stations to communicate with a base station through intermediate relay stations.

- **MMR-base station (MMR-BS):**
  A base station that is compliant with amendment IEEE 802.16j to IEEE Standard 802.16e.

- **relay station (RS) types:**
  - **fixed relay station (FRS):**
    A relay station that is permanently installed at a fixed location.

 - **nomadic relay station (NRS):**
    A relay station that is intended to function from a location that is fixed for periods of time comparable to a user session.

  - **mobile relay station (MRS):**
    A relay station that is intended to function while in motion.

Distinction from the others

- **802.16mmr**
  - **interworks with the others following 802.16, and**
  - **different from those of 802.1D, 802.1Q, 802.1ad and 802.11s,**
  - **happy to work together with those, if necessary.**
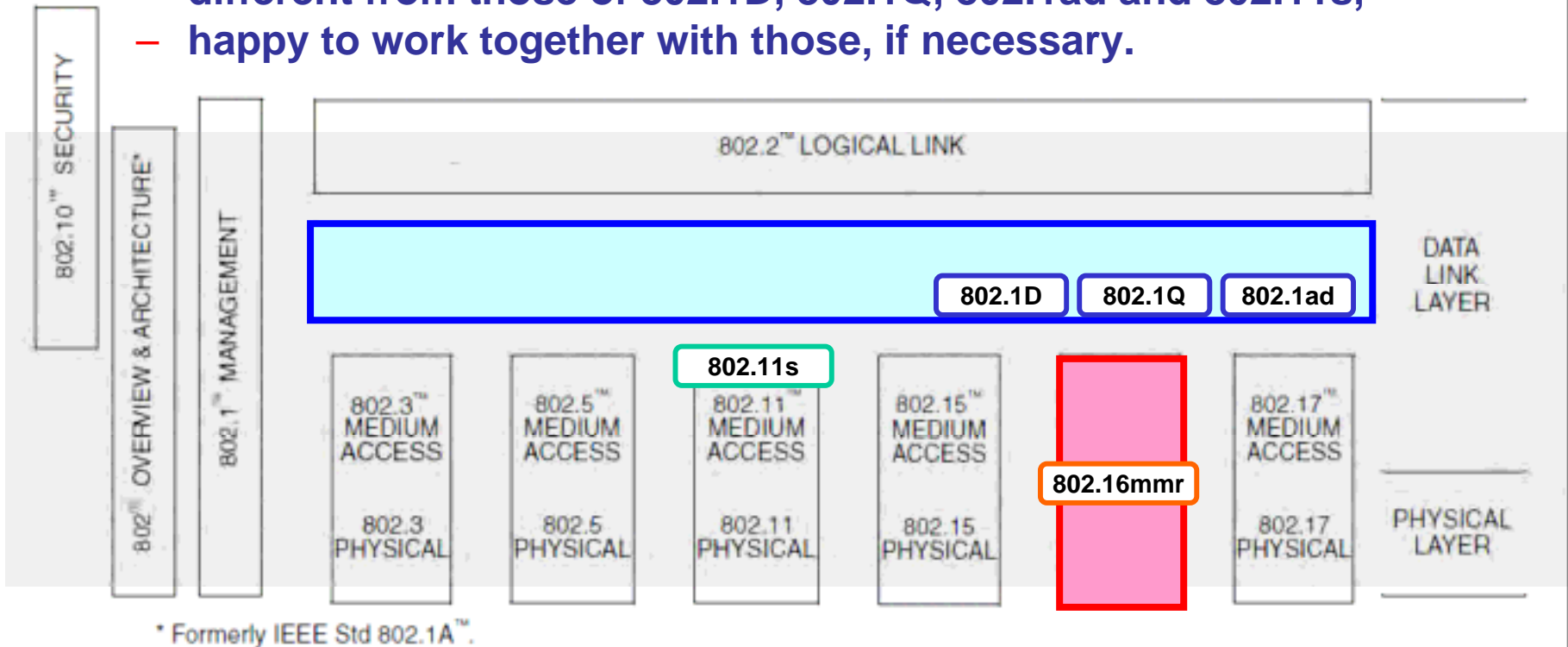
The relationship between the IEEE standards

Reference: IEEE Std 802.1Q-2003 (p. iii)

MMR Study Topics

- **Key items**

  - **Introduction of a relay station**

    RS pretends to be a BS for MS and to be a MS for BS

  - **Modification to BS (MMR-enhanced BS)**

    Add a function to communicate with a relay station

- **Working scope**

  - **PHY: Enhance normal frame structure**
  - **MAC: Add new protocols for the Relay**

* **Study on technical details such as Frame Structure, Mobility/Handover Support, QoS, etc., to come.**

Tentative Schedule

Year	Month	802.16 session	Actions
2006	**Jan.**	**#41 Interim**	**SG: the 3rd meeting – PAR Completion**
	Mar.	**#42 Plenary**	**Tutorial Session on 802.16 MMR** **802 EC to approve 802.16j PAR**
	May	#43 Interim	1st TG meeting
	July	#44 Plenary	2nd TG meeting Require Document & Procedure for proposal Selection & merging
	Call for Contribution		
	Sept.	#45 Interim	3rd TG meeting Presentation & Selection
	Drafting standard		
	Nov.	#46 Plenary	1st WG letter ballot
2007	Jan.	#47 Interim	2nd WG letter ballot
	Mar.	#48 Plenary	1st sponsor ballot
	May.	#49 Interim	Sponsor Recirculation
	July.	#50 Plenary	Submission to Rev. Com
	Sep.	#51 Interim	SA Approval

Summary

- **Presented the 802.16 MMR Overview, referring to the 802.16j PAR & 5 Criteria:**

➢ **Main Features**

- Terminals that can talk with RS: **Conventional .16 MS/SS only**
- Modulation: **OFDMA only**
- RS Type: **fixed, nomadic and mobile**
- Tree structure: one of the end of relayed data path should be at BS
- Backward compatible to PMP mode
- Efficiently provide Relay connection to MS (with small number of hops)

➢ **Working Scope**

- PHY: Enhance normal frame structure
- MAC: Add new protocols for the Relay

IEEE 802 Tutorial:

802.16 Mobile Multihop Relay
- Economic Feasibility and Serviceability-

Speaker: Jose Puthenkulam (jose.p.puthenkulam@intel.com)

Contributors: M. Asa, P. Jain, R. Peterson, J. Puthenkulam, S. Ramachandran, A. Sharon

Additional significant contributions by K. Johnsson, H. Lee, D. Chen, F. Favichia, M. Kibria, N. Natarajan, K. Singh, J. Sydir, A. Tang, and W. Wong

Outline

- **Economic Motivation of MMR**

  – **Potential Market of 802.16**

  – **Problems inherent in current solutions**

  – **Benefits of MMR**

- **Economic Analysis of MMR vs. Conventional WiMax**

  – **Network architecture and assumptions**

  – **Capacity enhancement**

  – **Coverage extension**

- **Summary**

Outline

- **Economic Motivation of MMR**
  - **Potential Market of 802.16**
  - **Problems inherent in current solutions**
  - **Benefits of MMR**
- Economic Analysis of MMR vs. Conventional WiMAX
  - Network architecture and assumptions
  - Capacity enhancement
  - Coverage extension
- Summary

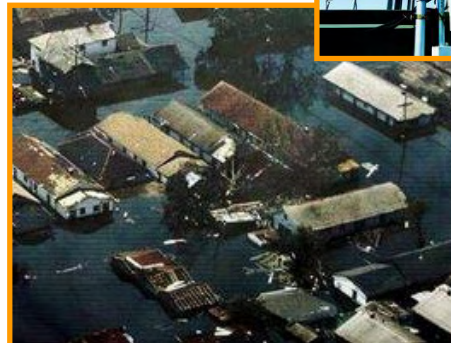# Future wireless applications require high bandwidth, low latency, reliable packet transfer…

CONSUMER:
Wireless DSL (WiMAX)
Voice / Data / Video
Inter-Device communications (UWB)
Streaming Video / 3D Gaming
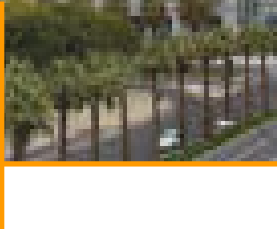
ENTERPRISE:
Unwired Offices and Factories
Connected Mobile Devices
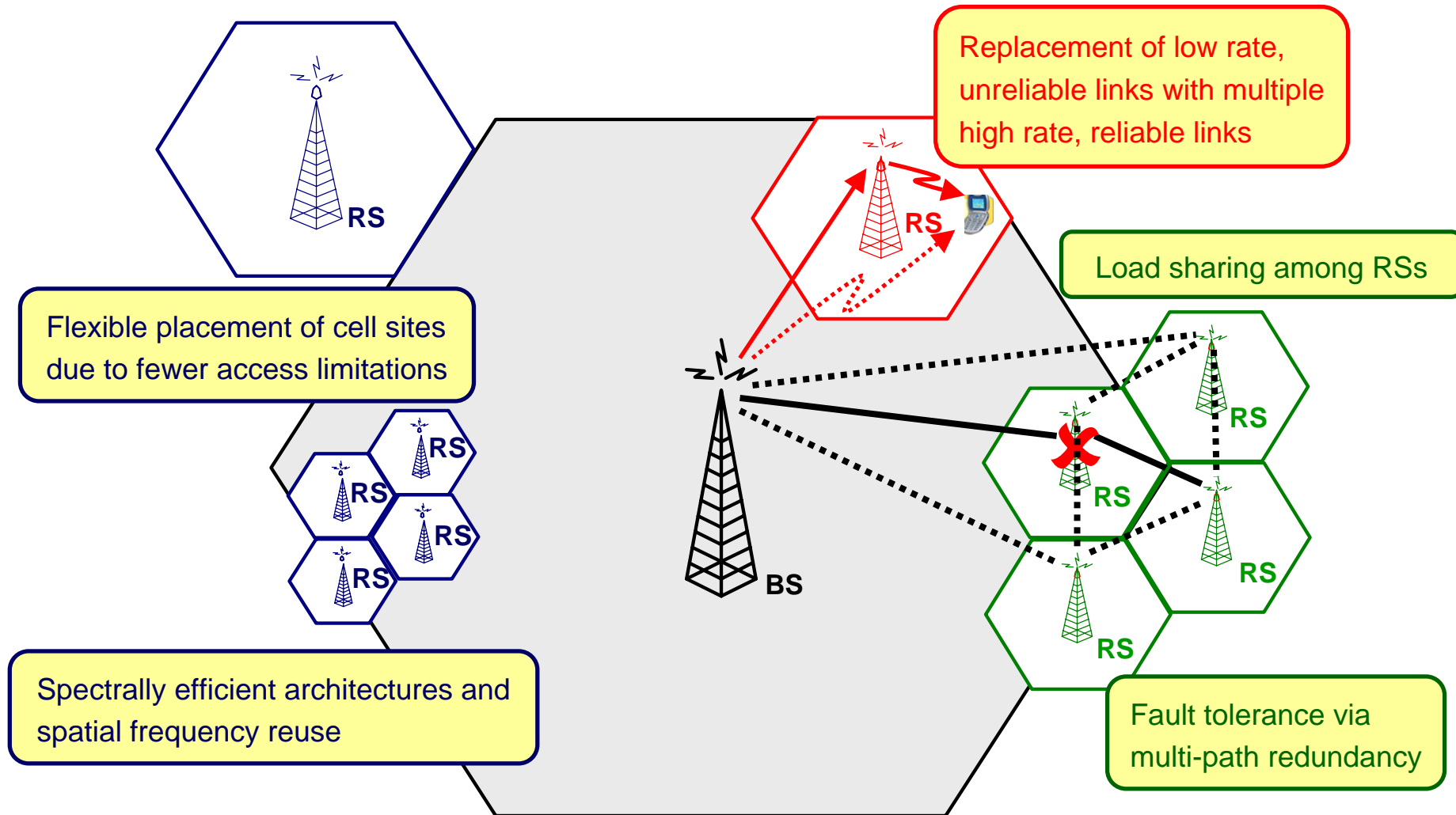Ubiquitous Wireless Connectivity

GOVERNMENT:
Law Enforcement
Disaster Relief

Realities of Current Cellular Deployments

- Current deployments suffer from …
  - Limited spectrum and/or insufficient wire-line capacity
  - Low SINR at cell edge
  - Coverage holes due to shadowing
  - Out-of-range clusters of users
  - Non-uniformly distributed traffic load (e.g. hot spots)
- Reducing cell size improves conditions, but issues are…
  - Limited availability of wire-line infrastructure in developing markets
  - Limited access to traditional cell site locations
  - Prohibitive installation and operating costs (backhaul is large fraction)
- Providing fault tolerant service is difficult and expensive
  - Redundant equipment, backhaul, backup power at cell sites is costly

MMR Rationale:
Economical Coverage, Capacity, and QoS Enhancement

Replacement of low rate, unreliable links with multiple high rate, reliable links

Load sharing among RSs

Flexible placement of cell sites due to fewer access limitations

Spectrally efficient architectures and spatial frequency reuse

Fault tolerance via multi-path redundancy

RS

BS

Economic Benefits of MMR

- Lower Capital Expenditures (CapEx) and Operational Expenditures (OpEx)
  - Wireless backhaul
  - Better trunking efficiency at aggregate points
    - Wire-line OpEx does not scale linearly with capacity
    - Example: DS3 (~30 x DS1 data rate) is only 3x in cost
  - Lower site acquisition costs
  - Less costly antenna structure for RS
 - Lower cost and complexity of RS
  - Faster deployment

- Improved ROI

  Relay augmented network could provide higher ARPU through higher grades of service at lower overall incremental cost

Outline

- **Economic Motivation of MMR**

  - **Potential Market of 802.16**

  - **Problems inherent in current solutions**

  - **Benefits of MMR**

- **Economic Analysis of MMR vs. Conventional WiMAX**

  - **Network architecture and assumptions**

  - **Capacity enhancement**

  - **Coverage extension**

- **Summary**

Network Architecture

MMR
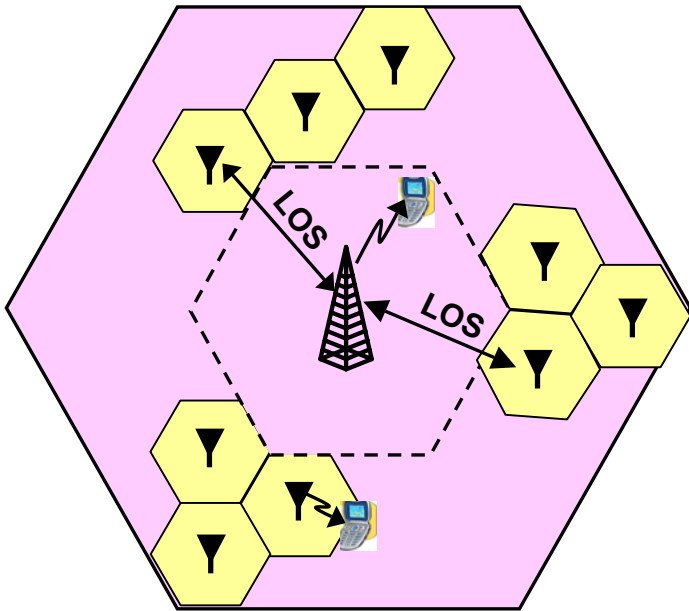
Conventional WiMAX
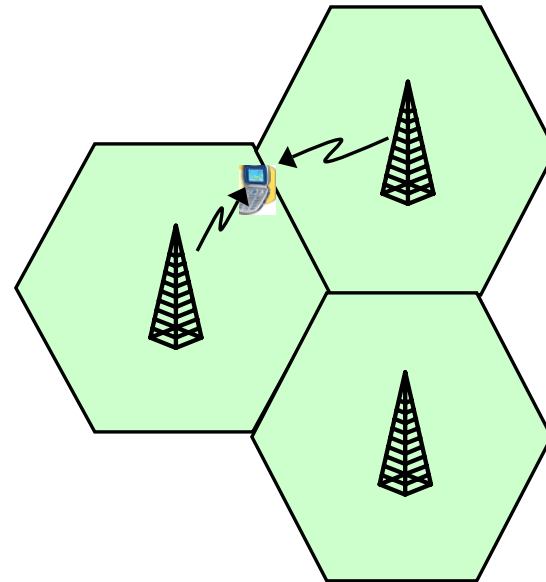
Legend

Relay Station Cell

MMR Base Station Cell

Base Station Cell

CapEx and OpEx Assumptions

		Conv. WiMAX	MMR	
		BS Cell	MMR-BS Cell	RS Cell
CapEx	Site acquisition & construction per cell	Current value	Same	<<
CapEx	Wired backhaul provision **(depending on wired backhaul traffic assumptions)**	Current value	>	N/A
CapEx	Base station	Current value	>	<<
OpEx	Administrative, backhaul, access points, and network costs	Current value	Same	<<

Legend: **>** **greater than**

<< **significantly less than**

Study Assumptions

- ## Conventional WiMAX
  - 30 MHz access bandwidth at 3.5 GHz
  - Spectral efficiency 5 bps/Hz
  - Range 136 dB, cell size dimensioned for min 3.7 dB SNR at edge
  - Cell splitting to meet capacity demand
- ## MMR
  - Ratio of MMR-BS to RS is 1:56, 1:33, or 1:12
  - MMR links at 2.4 and/or 5.8 GHz unlicensed bands
    - Unlicensed bands only for study purposes
    - LOS
    - High spectral efficiency due to reuse, scheduling, AFS, AAS, MIMO…
  - Access bandwidth at 3.5 GHz
    - MMR-BS: 20 MHz with 5 bps/Hz spectral efficiency
    - RS: 10 MHz with 2 bps/Hz spectral efficiency
 - MMR-BS range 136 dB, RS range 118 dB, min 3.7 dB SNR at edge

Case Scenarios

- ## Heavy Traffic, Urban Environment
  - Capacity limited
  - Traffic load is still less than capacity of MMR deployment
  - Deployments
    - MMR-BS cell structure dimensioned for min 3.7dB SNR at cell edge
    - Conv. WiMAX cell structure splits aggressively due to high traffic demand

- ## Light Traffic, Urban/Suburban/Rural Environment
  - Range limited
  - Traffic load based on mix of current customer demand and varying customer densities
  - Deployments
    - MMR-BS cell structure dimensioned for min 3.7dB SNR at cell edge
    - Conv. WiMAX cell structure splits modestly due to low traffic demand

CapEx and Year 7 OpEx of MMR vs. Conventional WiMax (Heavy Traffic, Urban Environment)

- MMR CapEx
- MMR OpEx
- Conv CapEx
- Conv OpEx

Relative Cost (normalized w.r.t. 1st bar)

Number of RS per MMR-BS
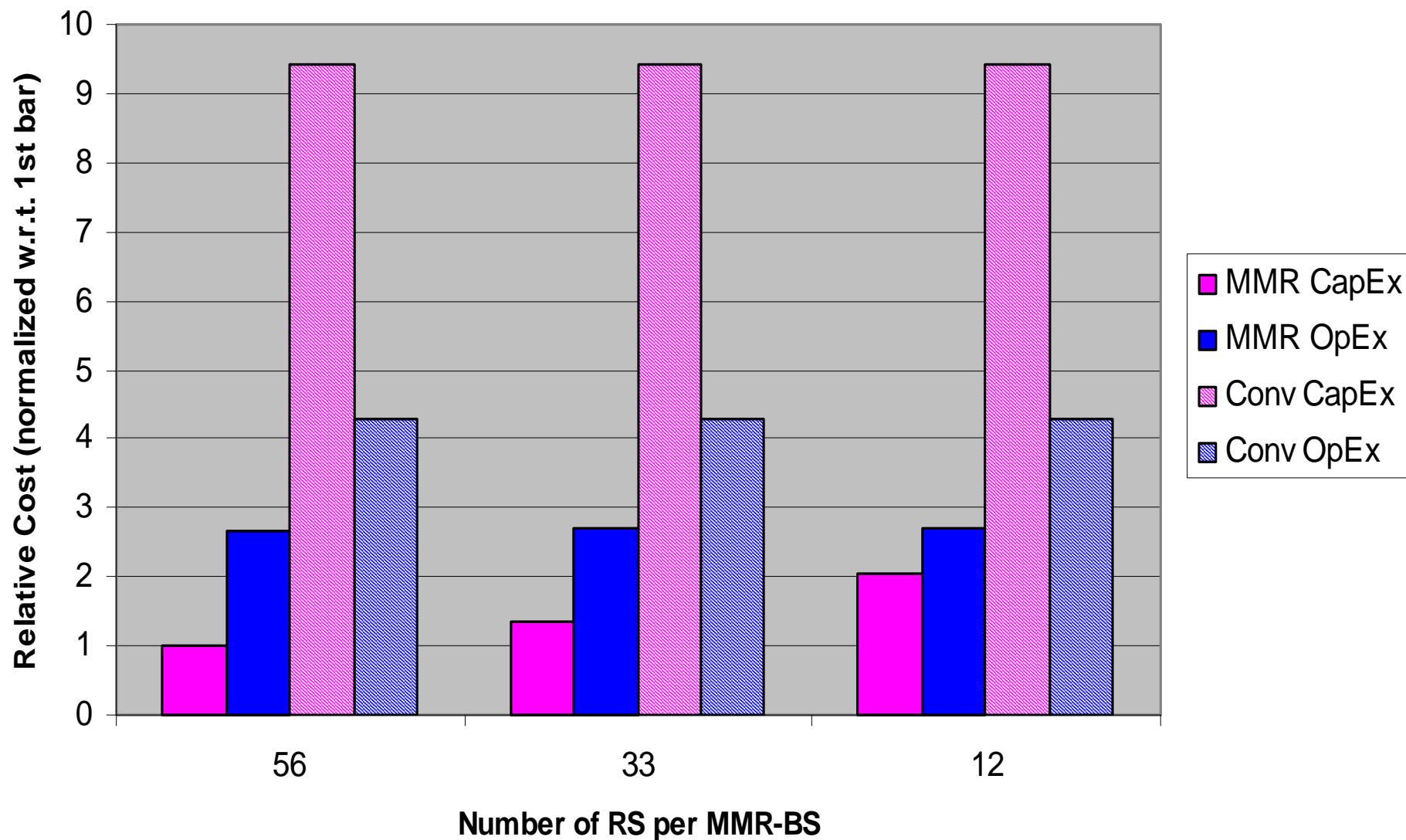
CapEx and Year 7 OpEx of MMR vs. Conventional WiMax (Light Traffic, Urban/Suburban/Rural Environment)
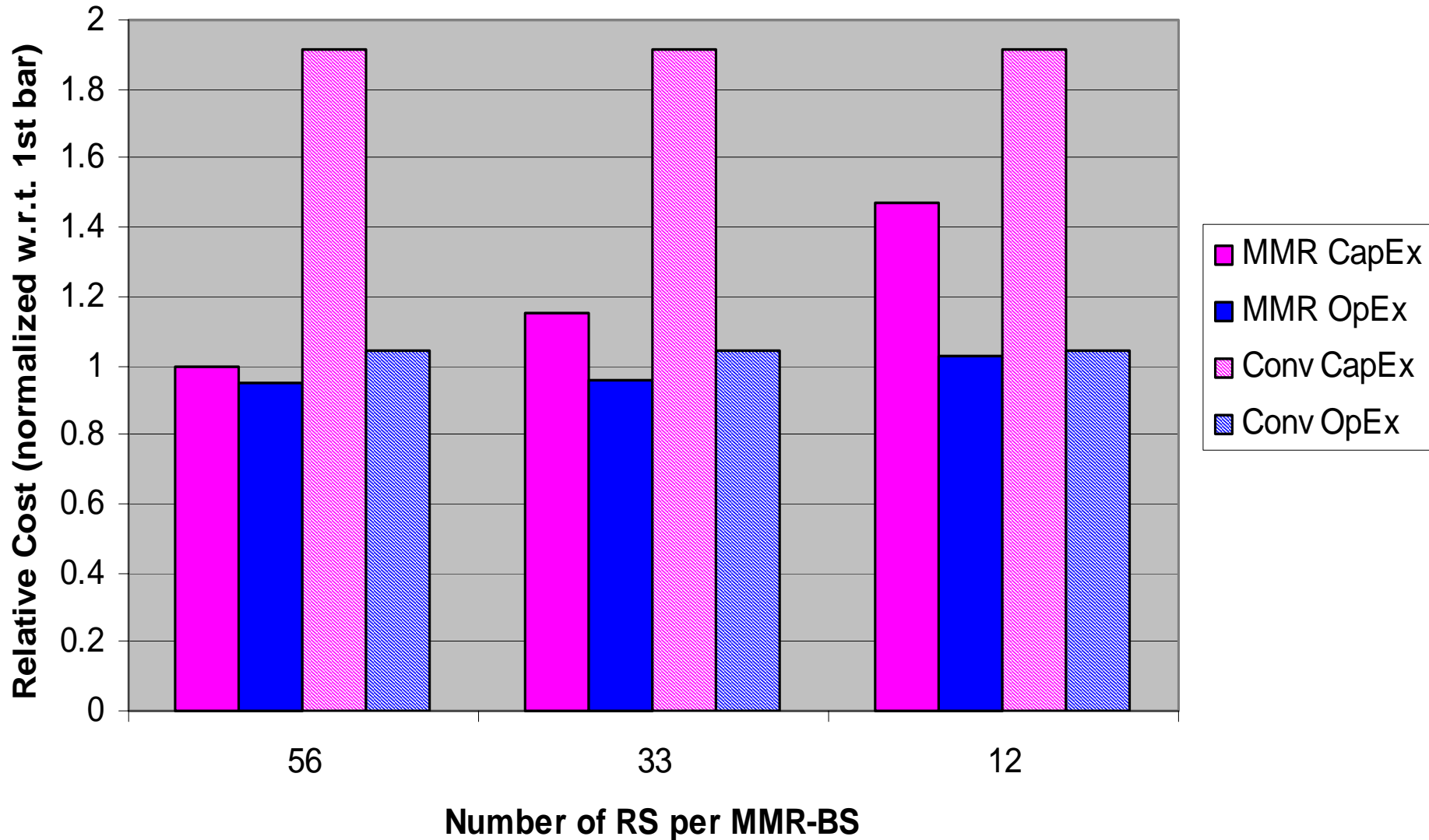
Study Conclusions

- **Conventional WiMAX**
    - CapEx a significant cost relative to OpEx

- **MMR**
    - CapEx grows with decreasing MMR-BS:RS ratio
    - CapEx only slightly larger than OpEx under light load
    - CapEx considerably less than OpEx under heavy load

- **Comparison of MMR and Conventional WiMAX**
    - *CapEx and OpEx of MMR always less than conventional WiMAX*
    - Economic gains from capacity improvement significantly larger than those from range extension

Summary

- ## 802.16 MMR

  - Achieves *cost-efficient* coverage, capacity, and QoS enhancement

  - Solution based on 802.16 compliant wireless backhaul

- ## MMR vs. Conventional 802.16 Case Studies

  - Includes financial/technical model and CapEx/OpEx analysis

  - Demonstrates the economic feasibility of MMR

  - Shows large economic gains compared to conventional 802.16

  - Indicates MMR economic advantage increases with traffic load

IEEE 802 Tutorial:

802.16 Mobile Multihop Relay
- Technical Study & Feasibility -

Speaker: Mike Hart (mike.hart@uk.fujitsu.com)

Co-authors: M. Asa, J. Cho, I.K. Fu, M. Hart, R. Peterson, J. Puthenkulam, S. Ramachandran, A. Sharon
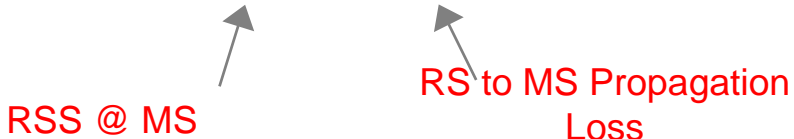
Contents

- Theoretical analysis
  - Multi-hop gain: Coverage, throughput, system capacity
  - Factors that affect gain

- Application of multi-hop techniques to IEEE 802.16
  - Technical modifications within scope of project
  - Overview of RS types & capabilities
  - Additional technical requirements

- Simulation results
  - Set 1: Downlink coverage reliability
  - Set 2: Spectral efficiency & link capacity outage probability
  - Set 3: Cell throughput
  - Set 4: Signal quality, throughput & MS transmit power

- Summary

Theoretical Analysis

- It is possible to demonstrate through even a basic theoretical analysis that multihop techniques enable a link budget gain
- This gain can then be utilised to enable:
  - Improvement in range
  - Improvement in throughput
  - Reduction in transmit power

- In order to demonstrate this the following analysis is conducted:
  1. Impact on the total transmit power required to achieve a given received signal strength (RSS) at the MS
  2. Effect of RS position on achievable multihop gain
  3. Impact of relaying on received SNR for a (simple) amplify and forward relay

Received Signal Strength

- For a given MS receive sensitivity requirement, the Tx power at RS must be set such that:

$$P_{tx @ RS} = P_{rx @ MS} L_{RS-MS}$$
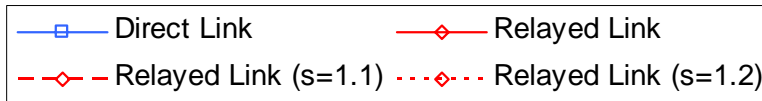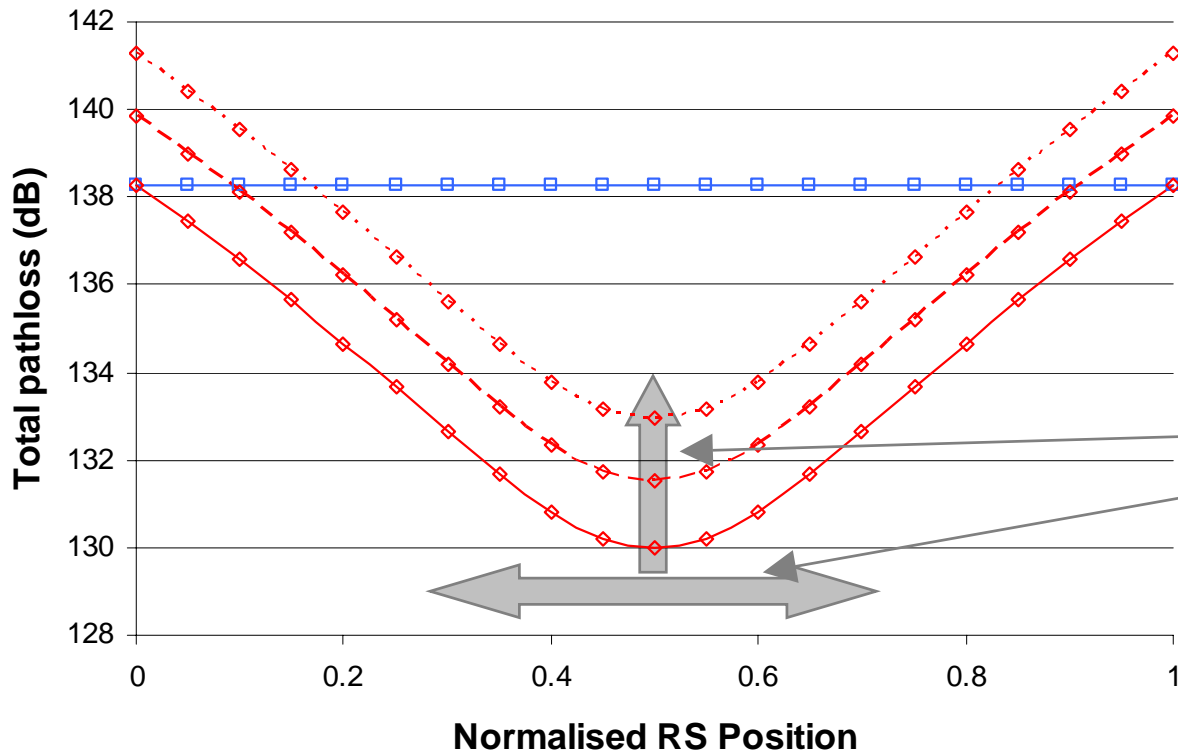
RSS @ MS

RS to MS Propagation Loss

- Assuming that the received sensitivity requirements at RS and MS are the same:

$$P_{tx,total} = P_{rx @ MS} \left(L_{BS-RS} + L_{RS-MS} \right)$$

- As a result it is possible to define:

$$G_{m-hop} = \frac{P_{tx,direct}}{P_{tx,relayed}} = \frac{L_{BS-MS}}{L_{BS-RS} + L_{RS-MS}}$$
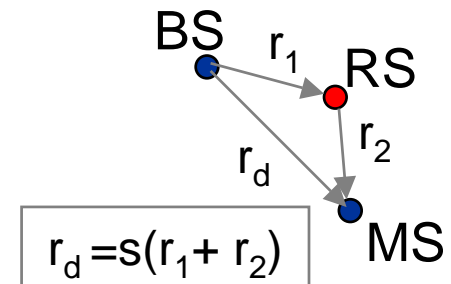
Pathloss Analysis: RS Position

Propagation loss model:

$$L(dB) = b + 10n \log r$$

Where: b=15.3, n=3.76

Effect of RS positioning

$r_d = s(r_1 + r_2)$

Received SNR

- For the case of an Amplify & Forward relay, the SNR at the MS is given by:

$$SNR_{MS} = \frac{P_{rx,MS}}{\left(N_{MS} + \dfrac{G_{RS} N_{RS}}{L_{RS-MS}} \right)}$$

Determines noise increase

- This can be re-written as:

$$SNR_{MS} = \frac{P_{tx,RS}}{L_{RS-MS}\left(N_{MS} + \dfrac{P_{tx,RS}}{SNR_{RS} L_{RS-MS}} \right)}$$
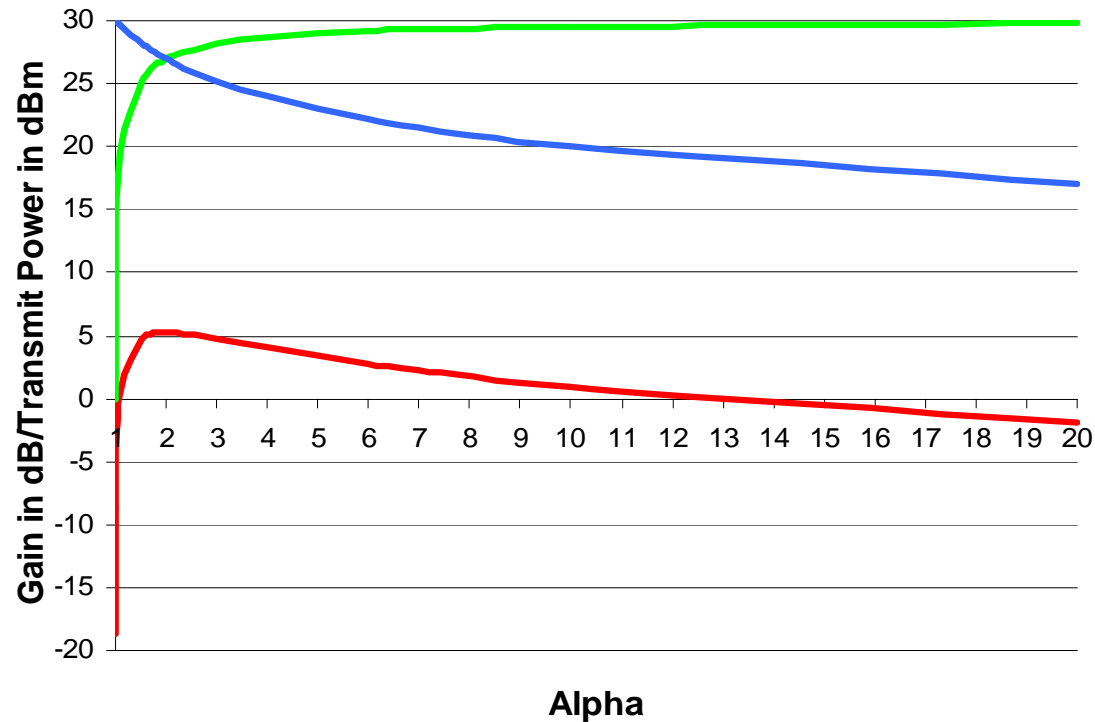
RS tx power

BS tx power

SNR at MS is a function of RS and BS transmit power

Received SNR

- Symmetrical pathloss parameters
- RS midway between
- BS and MS

For an A&F relay:
- SNR gain of ~5.3dB
- RSS gain of ~8.3dB

$$G_{SNR,m} = \frac{SNR_{MS,relayed}}{SNR_{MS,direct}} = \frac{L_{BS-MS}}{\alpha\left(L_{RS-MS} + \frac{L_{BS-RS}}{(\alpha-1)}\right)} \qquad \alpha = \frac{P_{tx,tot}}{P_{tx,RS}}$$

Summary

Analysis implies:

- For no increase in total transmit power:
  - → Range extension of an RSS
  - → Improvement in RSS at a particular point

  - OR -

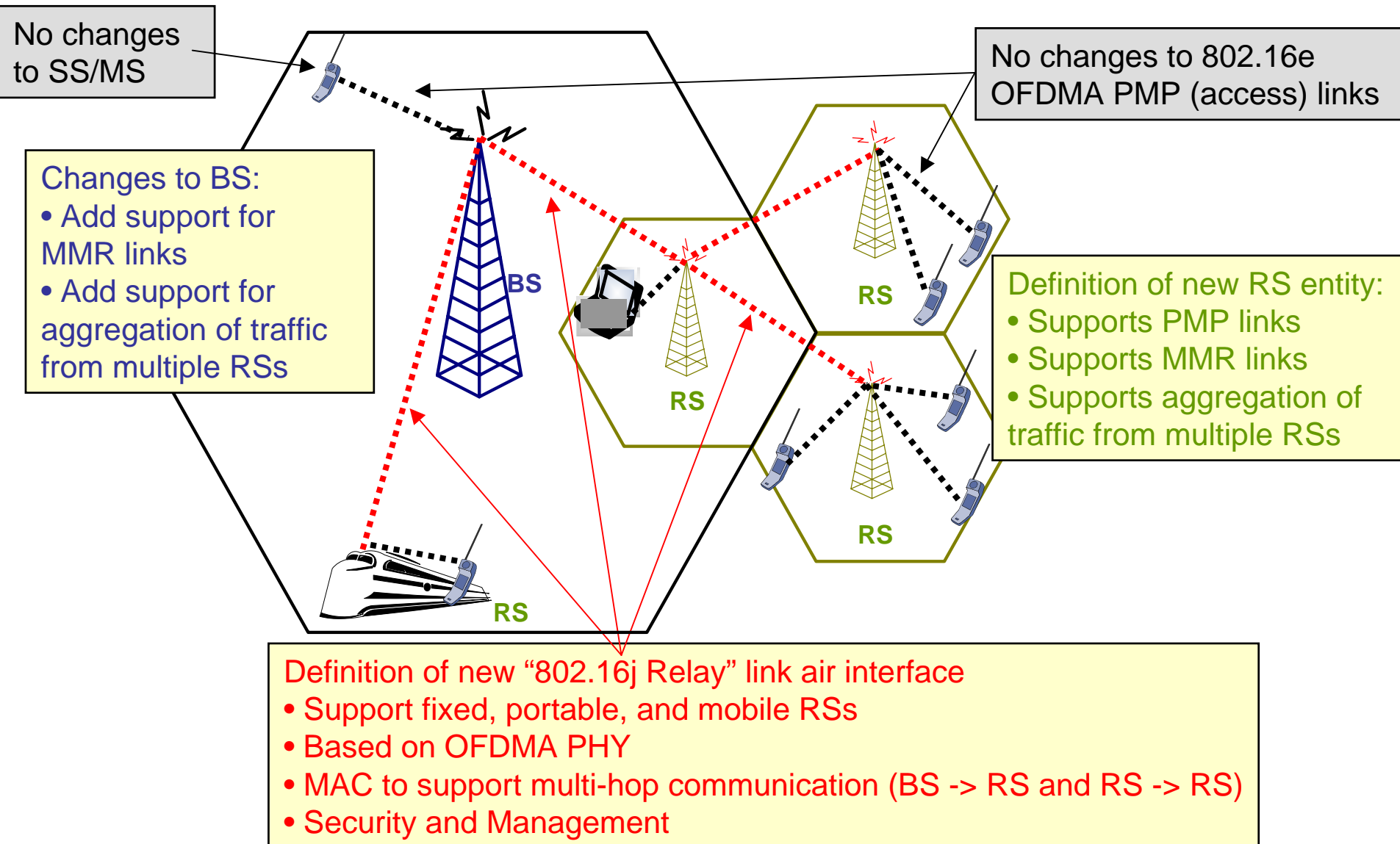- Reduction in transmit power to provide same RSS
  - → Reduction in the level of interference experienced

- Gain dependent on:
  - – RS positioning
  - – Propagation properties
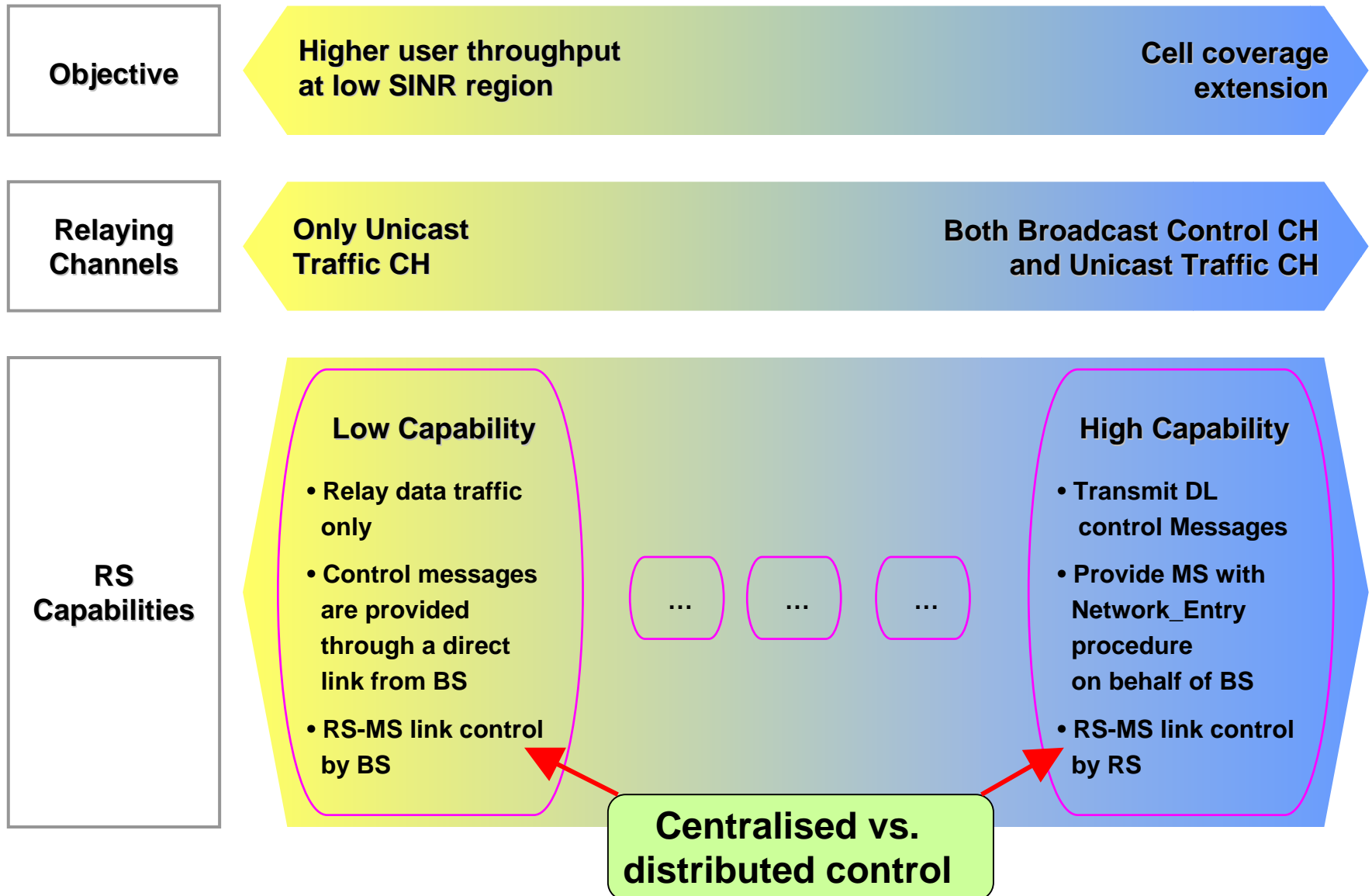 - – Transmit power setting

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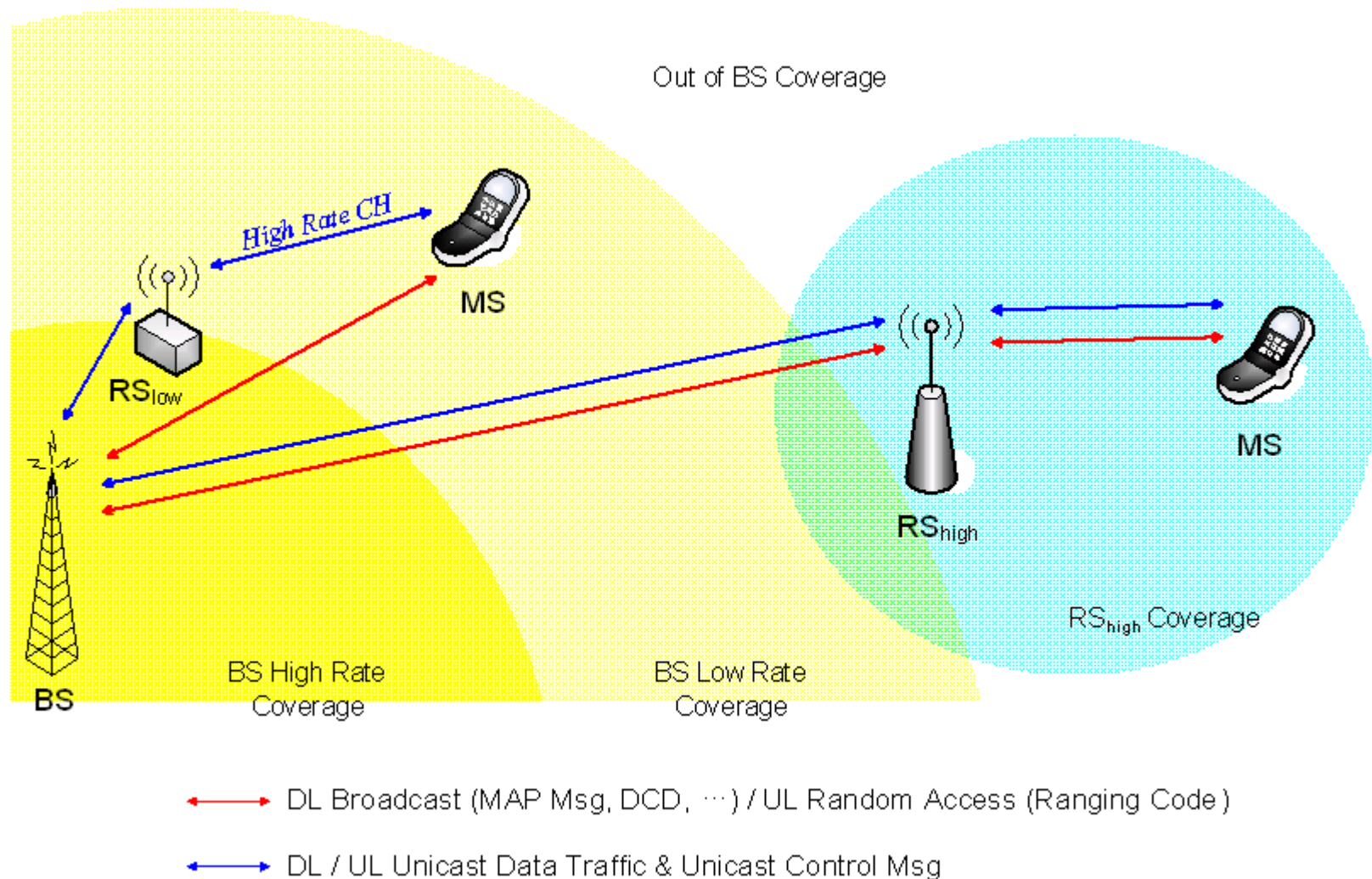- Summary

Scope of the 802.16j project

No changes to SS/MS

No changes to 802.16e OFDMA PMP (access) links

Changes to BS:
• Add support for MMR links
• Add support for aggregation of traffic from multiple RSs

BS

RS

RS

RS

RS

RS

Definition of new RS entity:
• Supports PMP links
• Supports MMR links
• Supports aggregation of traffic from multiple RSs

Definition of new "802.16j Relay" link air interface
• Support fixed, portable, and mobile RSs
• Based on OFDMA PHY
• MAC to support multi-hop communication (BS -> RS and RS -> RS)
• Security and Management

Potential RS types & capabilities

Objective	**Higher user throughput at low SINR region** → **Cell coverage extension**
Relaying Channels	**Only Unicast Traffic CH** → **Both Broadcast Control CH and Unicast Traffic CH**
RS Capabilities	

Low Capability

- Relay data traffic only
- Control messages are provided through a direct link from BS
- RS-MS link control by BS

... ...

High Capability

- Transmit DL control Messages
- Provide MS with Network_Entry procedure on behalf of BS
- RS-MS link control by RS

Centralised vs. distributed control

Example: Scenario vs. Capability

Technical Challenges/Requirements

- Routing
  - Centralized vs. distributed control
  - Supported topologies: hierarchical (tree) w/ multipath redundancy
- Scheduling, Radio resource management, Power control
  - Centralised vs. distributed control
- Call admission and traffic shaping policies
- Transport layer protocols for multi-hop networks
- QoS
  - Network-wide load balancing
  - Congestion control / flow control

Technical Challenges/Requirements

- Frequency usage considerations
  - PMP vs. Relay link frequency – shared or separate
  - Frequency planning
    - Interference mitigation in access (RS/MS) and BS/RS link
    - Frequency reuse / spatial multiplexing in BS/RS link
- Use of advanced antenna technologies
  - MIMO, beam forming
- Fault tolerance support
  - Network auto-reconfiguration under the control of BS
- Network management for portable / mobile RS
- Security considerations for portable / mobile RS

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Set 1: Downlink coverage reliability

Masahito Asa, Roger Peterson, Ariel Sharon, Shyamal Ramachandran

(Contact: asa@motorola.com)

Simulation scenario

- Focusing on control channel
- Model: 2 hop system with 6 relay stations
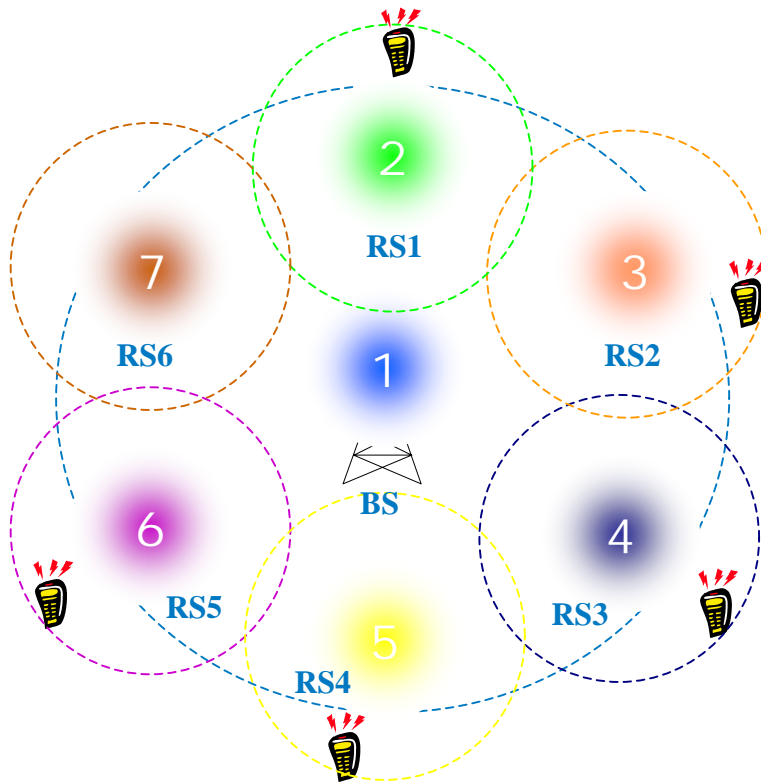
- Coverage reliability
  - CINR at 95% coverage
  - 95% of the users in a cell receive equal or more than the CINR value
- Assumptions
  - Frequency: 2.5GHz
  - Bandwidth: 10MHz
  - No sectorization (omni antenna)
  - BS-RS: Line of sight (LOS)
  - RS-MS, BS-MS: non-LOS
  - RS location: 0.6 x cell radius
  - Multi-cell (19 cells)
  - Route that provides max. received power at a MS was selected if multiple paths exist
  - 10,000 snap shots for each simulation

CINR Calculation for 2 Strategies

- **Single hop**
  - same as a generic synchronized cellular system
    - Signal: from the target BS
    - Interference:
      - intracell: no interference
      - intercell: from BSs in other cell

$$CINR = \frac{C_{\text{target\_BS}}}{\sum\limits_{\text{other\_cell}} I_{\text{BS}} + Noise}$$

- **Two hop**
  - Each RS transmits information sequentially in time
    - 7 time slots in a frame are required
    - Signal: from the target RS
    - Interference:
      - intracell: no interference
      - intercell: from one RS in each cell
        - » The RS in the same relative location to the BS

$$CINR = \frac{C_{\text{target\_RS}}}{\sum\limits_{\text{other\_cell}} I_{RS} + Noise}$$

Simulation Results
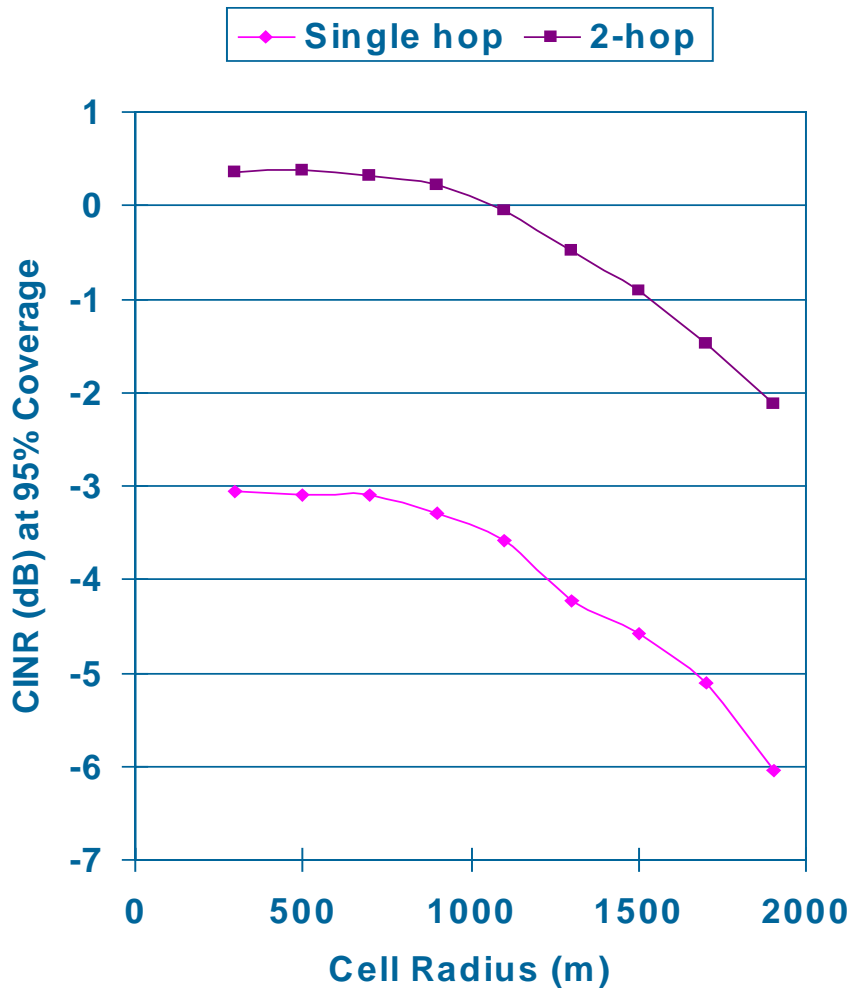
- Two hop system outperforms the single hop system in coverage reliability by more than 3dB
  - However additional radio resources are used for the transmission from a relay station
  - Radio resource management will be a key study item in future

Parameter values for simulation

Cell radius	Variable	Carrier frequency	2.5 [GHz]
Max. number of hops	2	Bandwidth	10 [MHz]
Multiplexing	TDD	Maximum power (BS/RS/MS)	43/40/20 [dBm]
Multiple access	TDMA	Antenna gain (BS/RS/MS)	10/10/0 [dBi]
Number of time slots	NA	Noise figure (BS/RS/MS)	5/9/7 [dB]
Number of cells	19	Pass loss model between	
Number of sectors	1 (no sectorization)	BS-RS, RS-RS	LOS
Cell synchronization	yes	BS-MS, RS-MS	Walfisch-Ikegami
Number of MS in a cell	10	Antenna height (BS/RS/SS)	50/30/1.5 [m]
Number of RS in a cell	6	Roof top height	25 [m]
BS-RS distance	0.6 x cell radius	Street width	20 [m]
RS mobility	Fixed	Separation bet. buildings	80 [m]
Number of RS antennas	1 (omni antenna)	Shadowing std. deviation	10 [dB]
		Shadowing corr. distance	50 [m]
		Shadowing corr. bet. cells	0.5

Set 2: Spectral efficiency & link capacity outage probability

(C802.16mmr-05/022 & C802.16mmr-06/015)

Jose Puthenkulam

(Contact: jerry.sydir@intel.com)

Setup and Assumptions

- Consider a one-dimensional network where an MMR-BS and MS/SS route data through multiple intermediate relay stations (decode and forward) located equidistantly.

- Channel model includes path loss, lognormal shadowing.

- No spatial reuse, no interference, no synchronization error is considered.

- Spectral efficiency C(i) denotes the maximum achievable rate per Hz during hop i.

- End-to-end spectral efficiency C is given by:

$$C = \frac{1}{\sum_{i=1}^{N} \frac{1}{C(i)}}$$

- Outage is defined as the event in which the achieved end-to-end data rate falls below the target data rate.

M-BS   RS 1   RS 2   RS 3   RS N   MS/SS
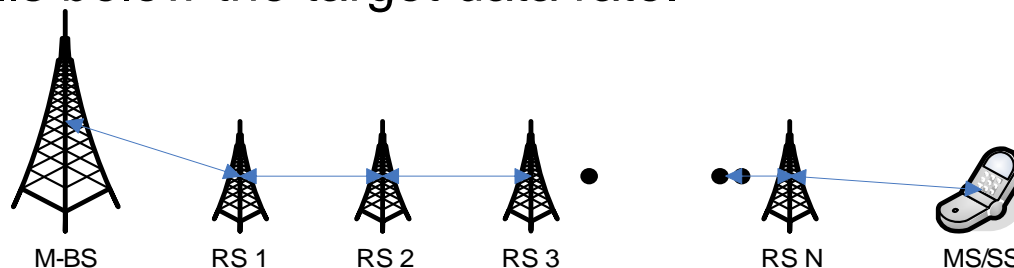
Spectral Efficiencies
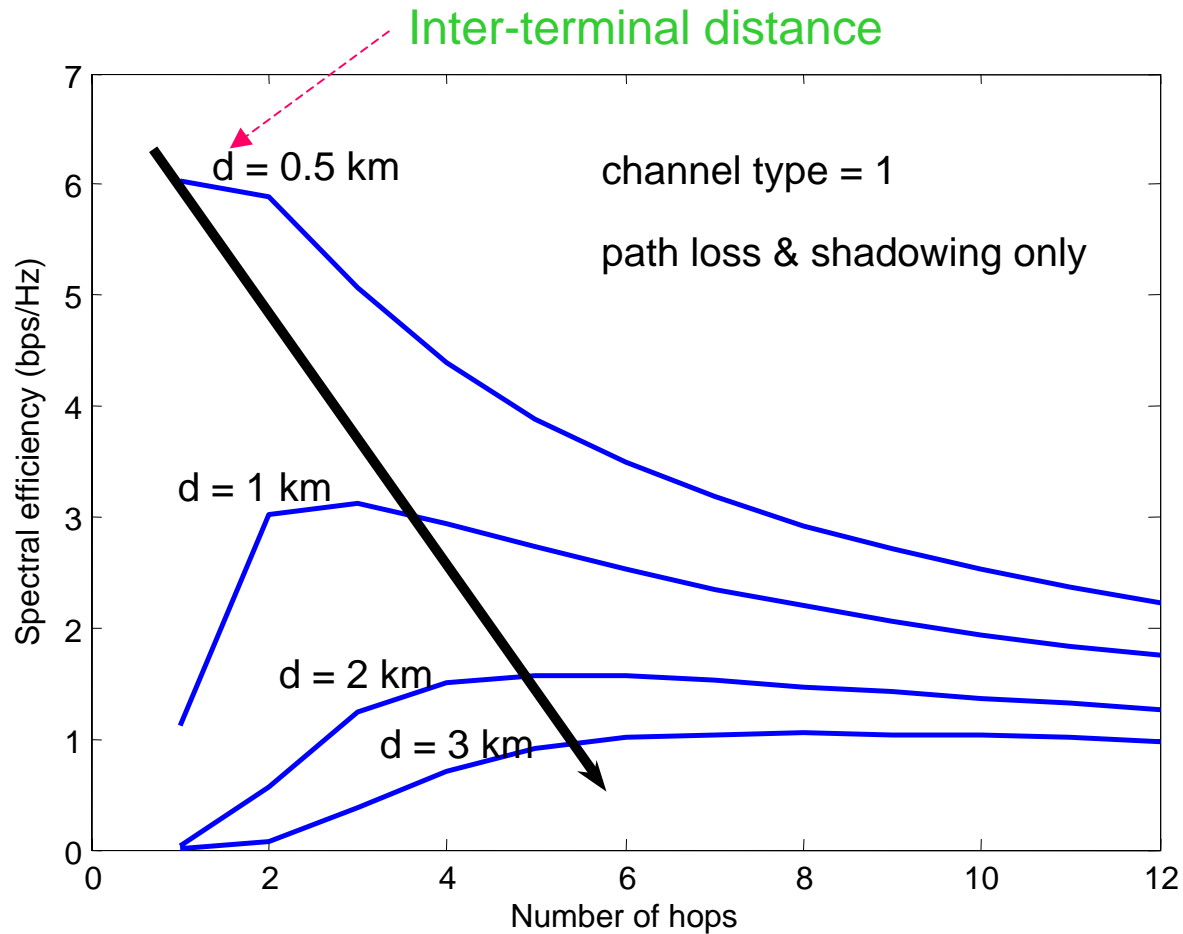
- RS helps to improve spectral efficiency

Outage Probability vs. Link Capacity

- RS reduces outage probability, increases system reliability and provides diversity

- MMR with no SS changes loses little in performance over MMR with SS changes

Subscriber selects best capacity BS/RS [BS-SS 750m, BS-RS 600m, RS-SS 250m]

Direct link w/o relay
Relay link with SS upgraded
Relay link with SS unchanged

Outage probability (CDF)

0.25
0.2
0.15
0.1
0.05
0

Relay gains w/o SS change

0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

End-to-end spectral efficiency (bps/Hz)
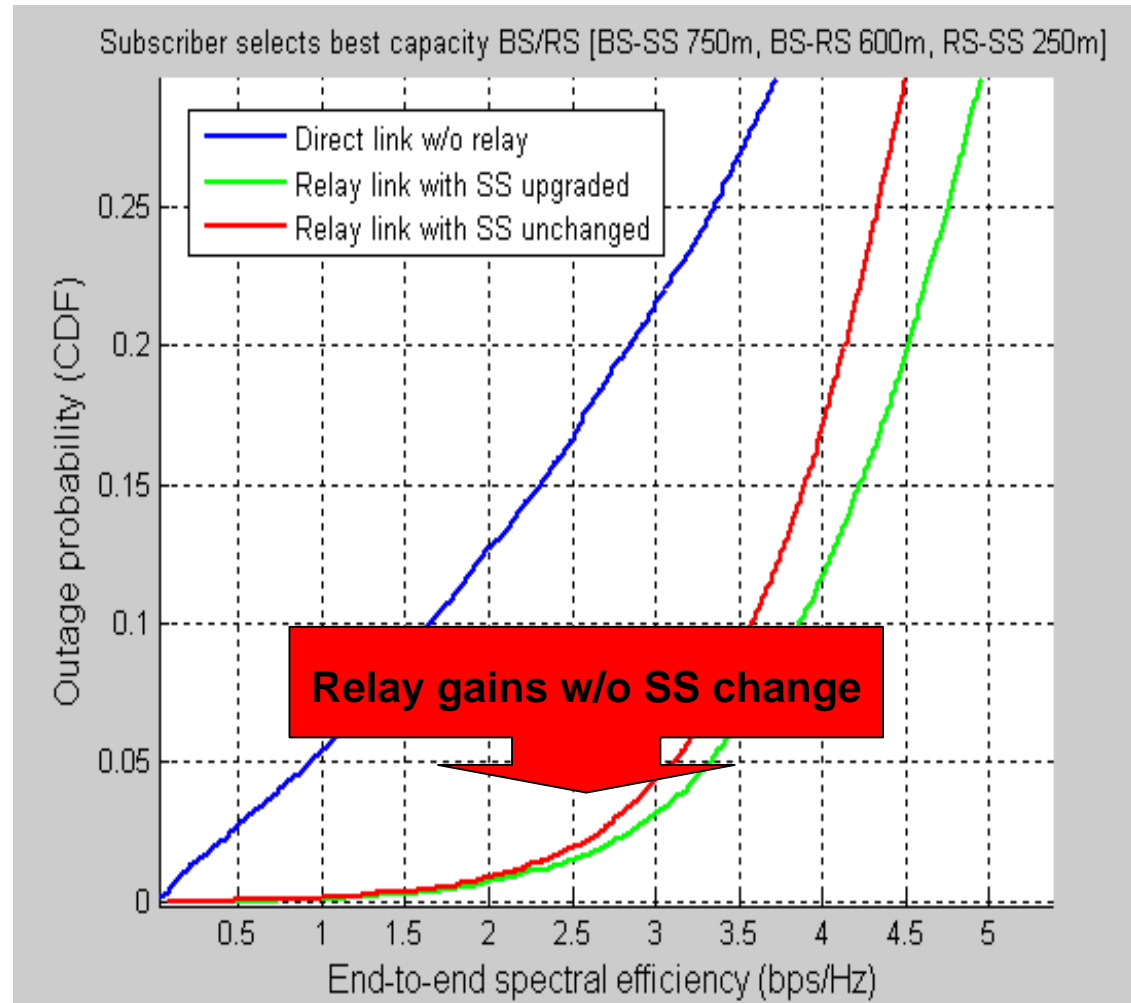
Set 3: Downlink & uplink cell throughput enhancement

(C802.16mmr-06/003)

Jaeweon Cho

(Contact: jaeweon.cho@samsung.com)

Overview

- This contribution shows an achievable throughput gain from 2-hop fixed relay
  - Coverage advantage is obvious and previously studied
  - Analysis results confirm that the fixed relay can provide capacity gain as well
- System model
  - Manhattan-like urban environment
  - TDD OFDMA based on IEEE Std 802.16e-2005
  - Infrastructure RS type
  - Rate adaptation control scheme for both down- and up-links
  - Full buffer model

Manhattan Urban Environment

- Deployment model
  - Total 49 BS's, Block size: 200 m, Road width: 30 m
  - Frequency reuse = 1

SINR (dB)

● BS
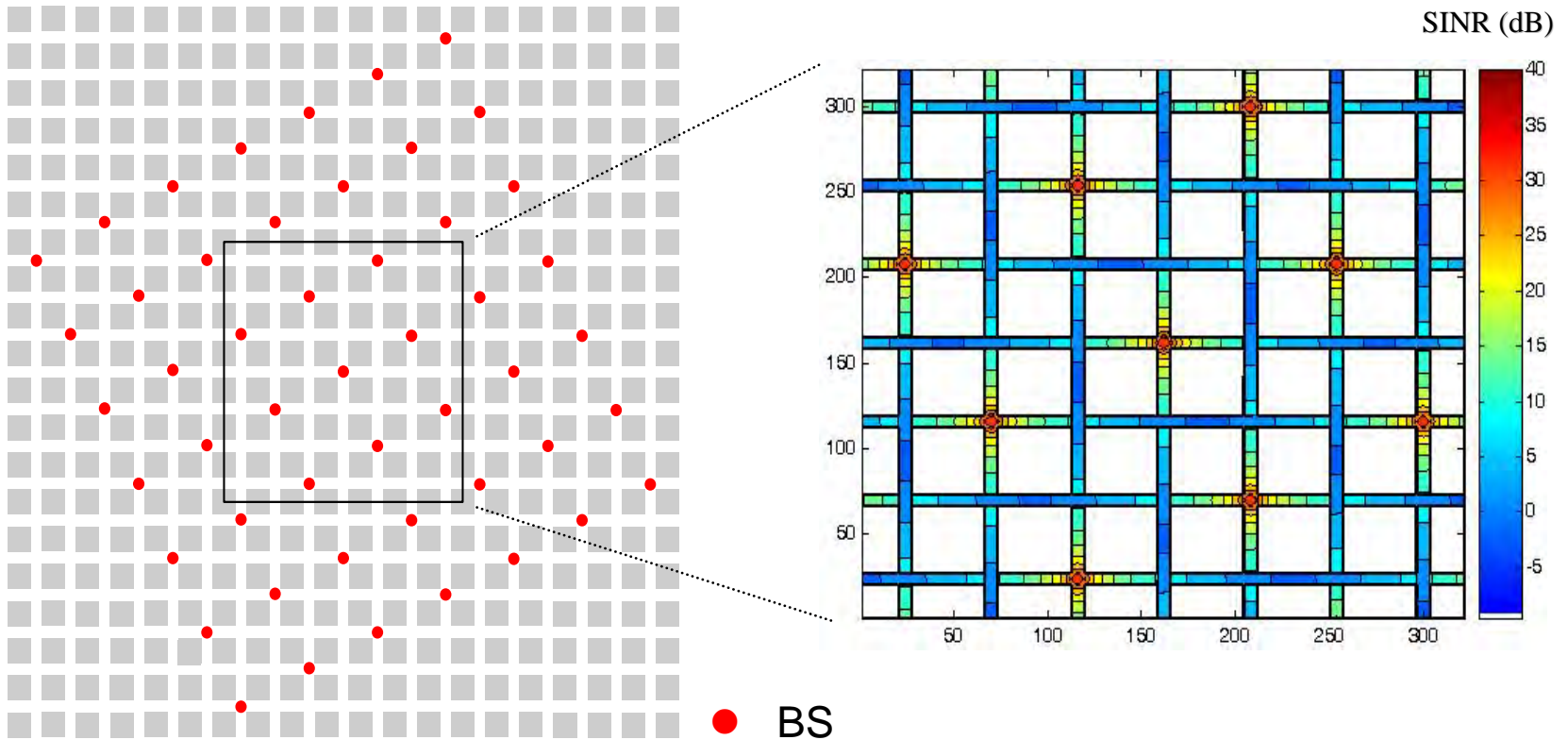
RS Deployment Model

- Number of RS's per BS = 4

- Frequency reuse factor among relays (K_r) = 1 or 4

  - K_r = 4: Different channel for each RS
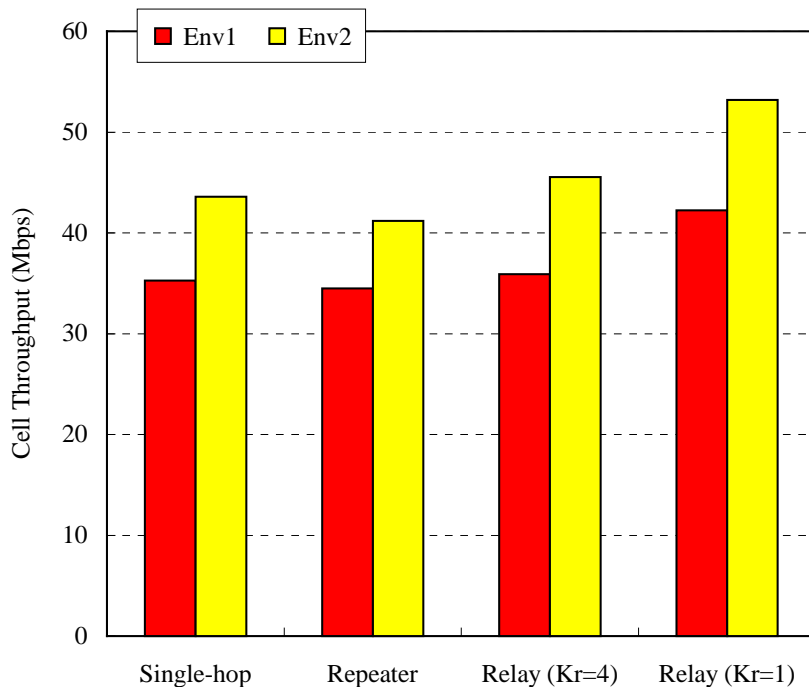
  - K_r = 1: Same channel for all RS's

BS deployment with RS's

- BS
- X RS
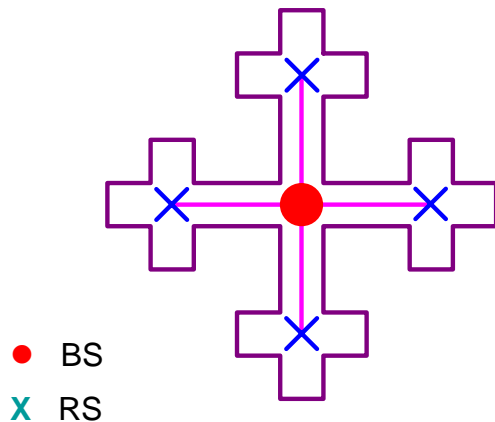
Statistical data from the center cell are collected.
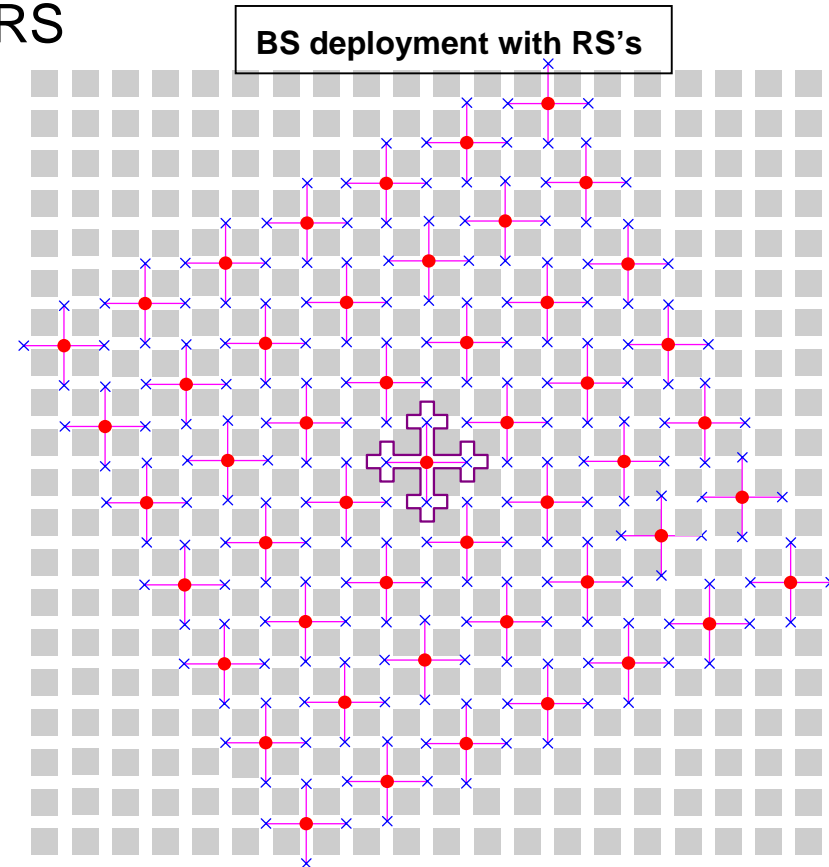
Cell Throughput

Downlink (with Shannon Capacity) — Uplink (with Shannon Capacity)
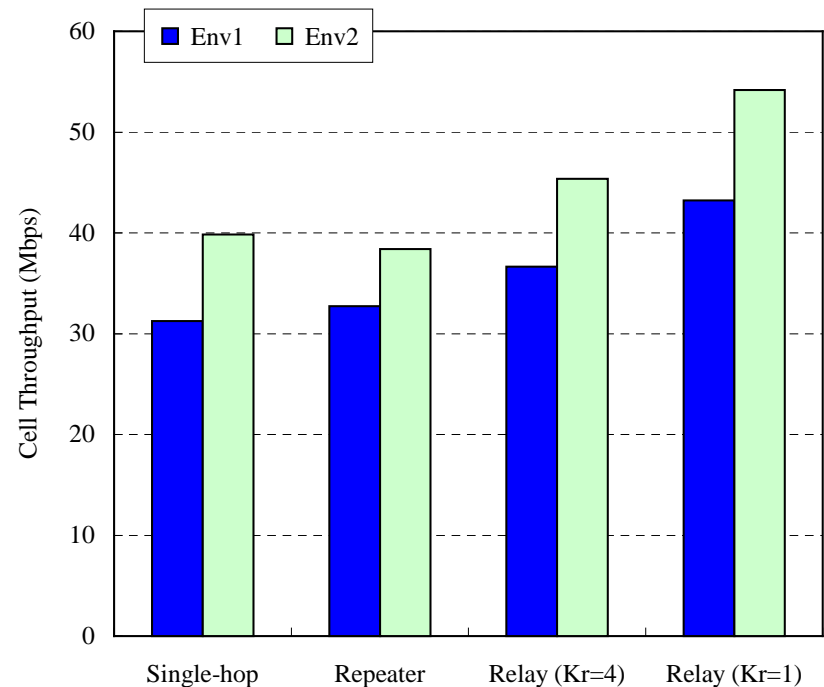
- Throughput enhancement (Relay with $K_r=1$ over single-hop)
  - In Env_1 (High BS/RS antenna model): 20% Downlink, 38% Uplink
  - In Env_2 (Low BS/RS antenna model): 22% Downlink, 36% Uplink

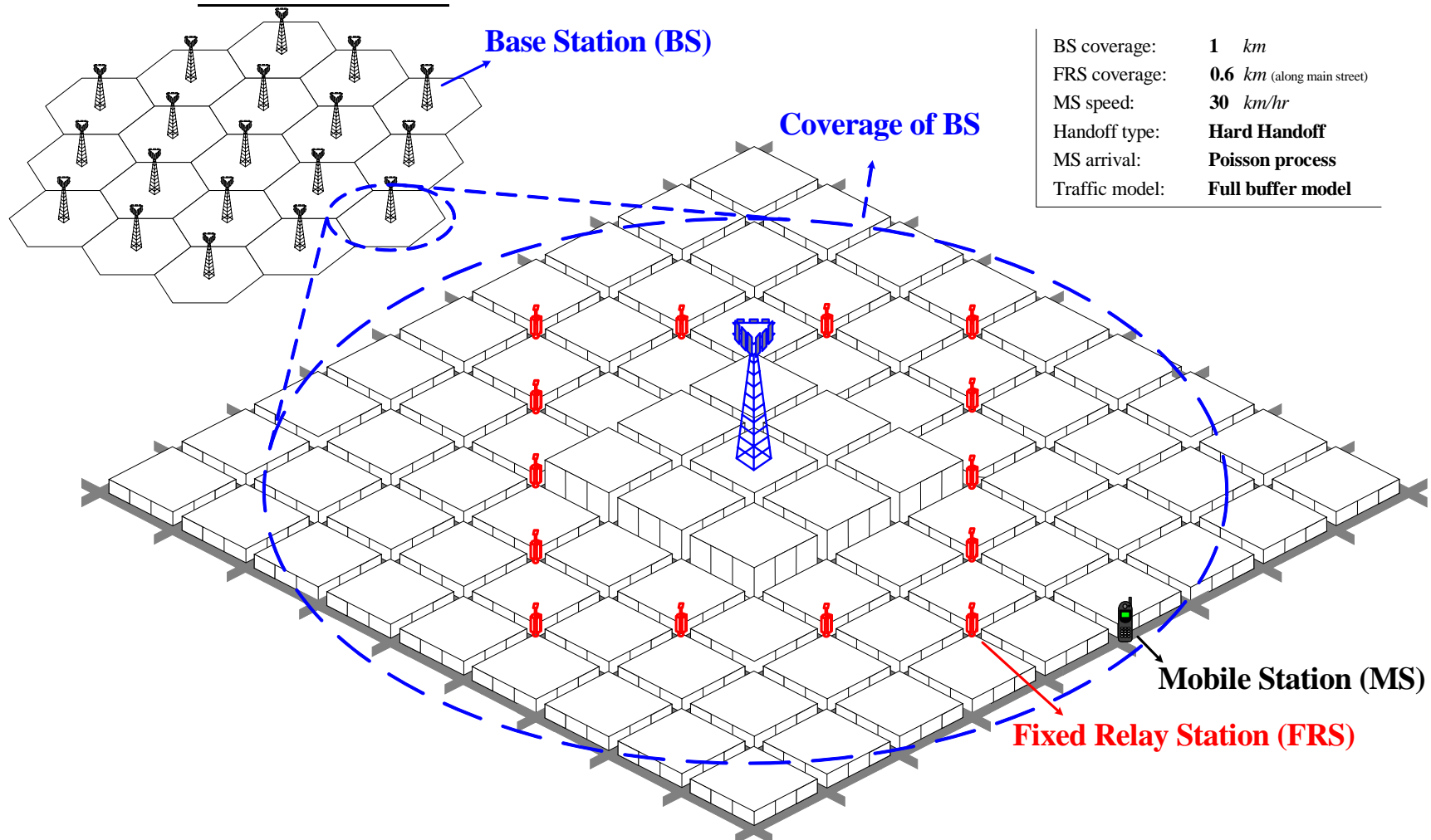# Set 4: Received signal quality, cell throughput & MS transmit power

(C802.16mmr-05/041 & C802.16mmr-06/004)

I-Kang Fu

(Contact: apatch.cm91g@nctu.edu.tw)

Simulation Scenario

- Relay Deployment Scenario
  - 14 <u>Fixed Relay Stations</u> are deployed within the coverage of each <u>Base Station</u>

Base Station (BS)

Coverage of BS

BS coverage:	**1**	*km*
FRS coverage:	**0.6**	*km* (along main street)
MS speed:	**30**	*km/hr*
Handoff type:	**Hard Handoff**	
MS arrival:	**Poisson process**	
Traffic model:	**Full buffer model**	

Mobile Station (MS)

Fixed Relay Station (FRS)

Simulation Environment

- Baseline system: IEEE 802.16e-2005 OFDMA mode
  - Models referenced from: C802.16mmr-05/041 & C802.16mmr-06/004
  - Propagation loss can be substantially reduced by LOS transmission when RS is deployed
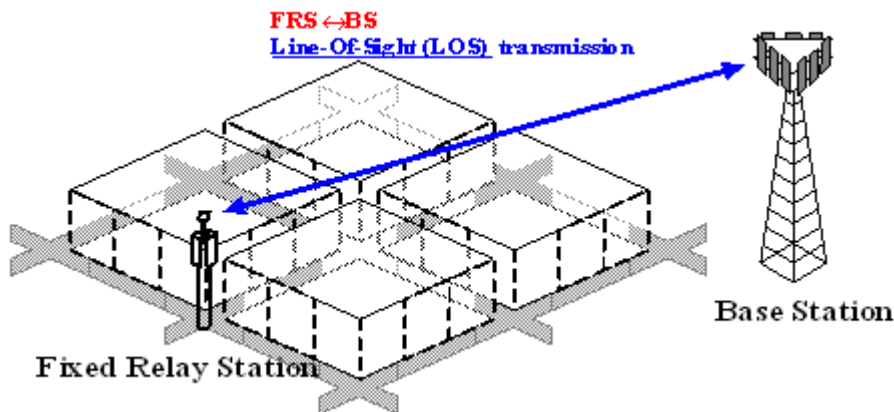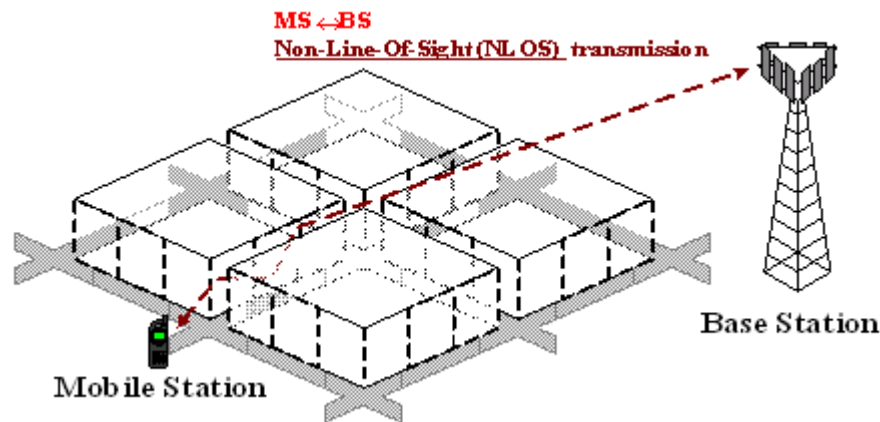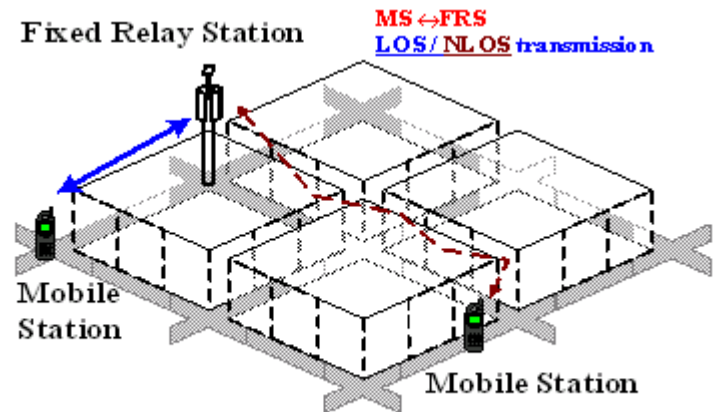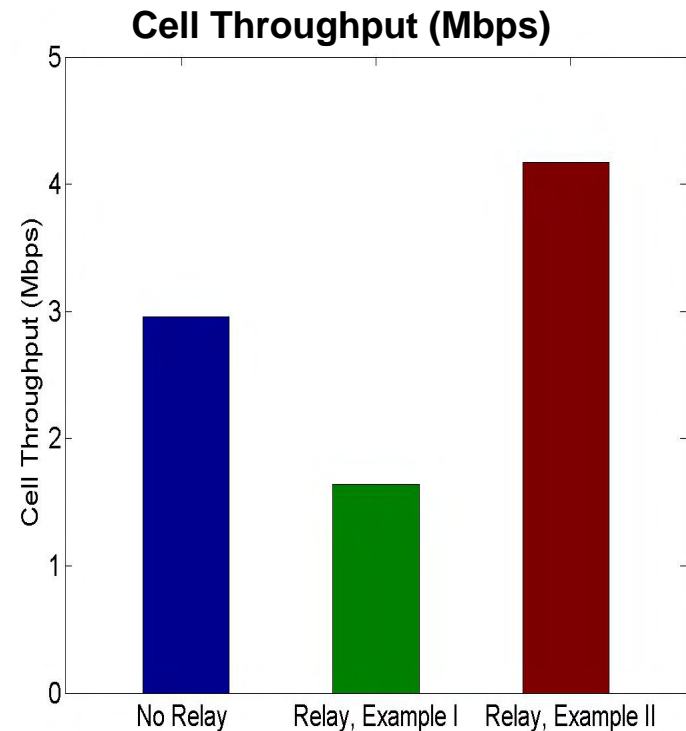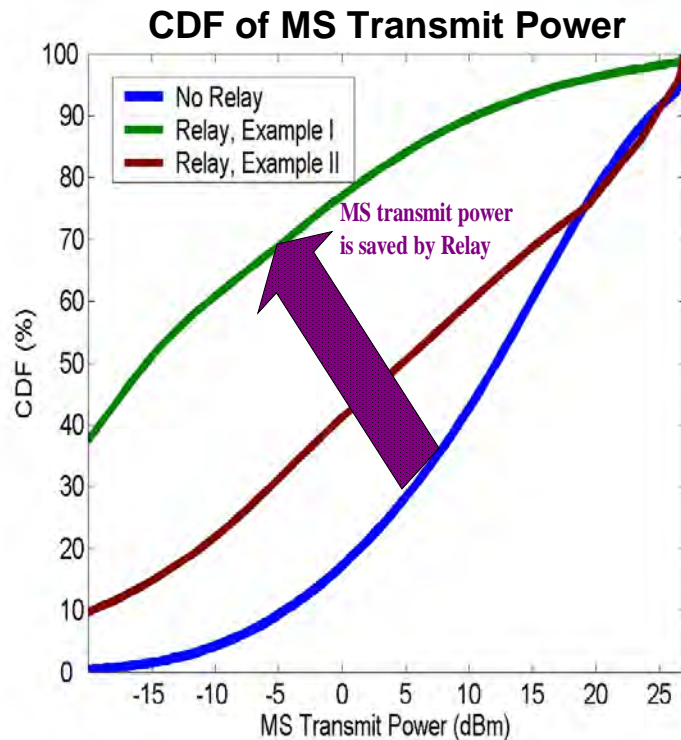
Simulation Results

- Downlink
  - Example I: Sub-channels are exclusively allocated to each FRS
  - Example II: All sub-channels can be reused by each FRS
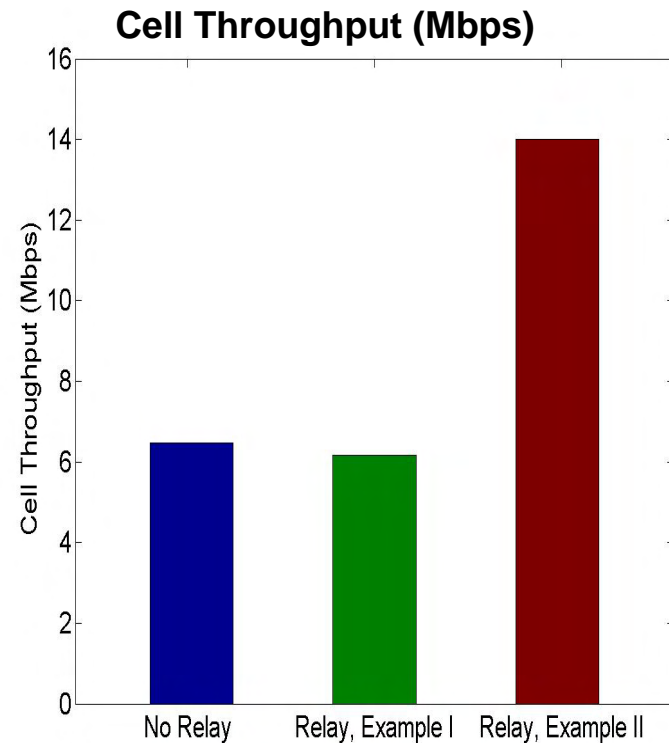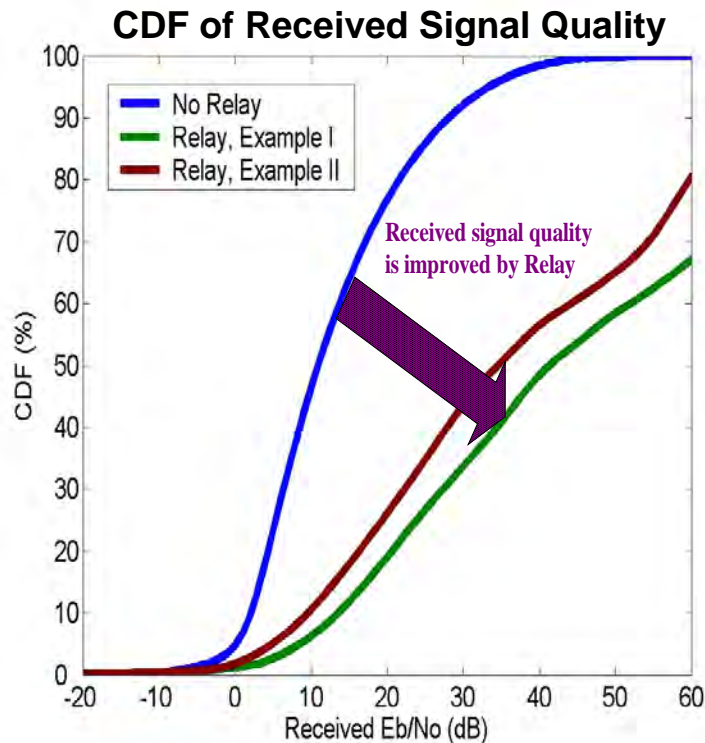
- Improvement on average received signal quality: **> 20dB**
- Throughput enhancement: up to **116.41%** (Example II)

Simulation Results

- Uplink
    - Example I: Only power control is considered
    - Example II: Both power and adaptive rate control are considered

CDF of MS Transmit Power

Legend:
- No Relay
- Relay, Example I
- Relay, Example II

MS transmit power is saved by Relay

Axes: CDF (%) vs MS Transmit Power (dBm)

Cell Throughput (Mbps)

Axes: Cell Throughput (Mbps) vs (No Relay, Relay, Example I, Relay, Example II)

- Average MS transmit power saved: ~ **10dB** (Example I)
- Throughput Enhancement: up to **41.66%** (Example II)

Contents

- Theoretical analysis
  - Multi-hop gain: Coverage, throughput, system capacity
  - Factors that affect gain

- Application of multi-hop techniques to IEEE 802.16
  - Technical modifications within scope of project
  - Overview of RS types & capabilities
  - Additional technical requirements

- Simulation results
  - Set 1: Downlink coverage reliability
  - Set 2: Spectral efficiency & link capacity outage probability
  - Set 3: Cell throughput
  - Set 4: Signal quality, throughput & MS transmit power

- Summary

Summary

- Multi-hop techniques can be used to:
  - Improve RSS: User throughput vs. range extension
  - Reduce total transmit power: Lower interference (improve CINR), longer MS battery life
- Degree of multi-hop gain is dependent on:
  - RS positioning & deployment environment
  - Setting transmit powers / allocating resources efficiently
- Enabling multi-hop will require new system features to be introduced to ensure realisation of the potential gain
  - End to end QoS management (throughput & latency)
- Early simulation results show that realisation is possible
  - Improve CINR coverage & improve spectral efficiency
  - Downlink & uplink cell throughput enhancement
  - Reduce MS transmit power