Integration of the Mobile Multihop Relaying in cellular networks

Integration of the MMR operations in the WiMAX system. The 802.16j specifications

Overview of MMR cellular networks

- Specifications required for:
  - Mobile multihop relay features;
  - Functions for multihop operations;
  - Interoperable relay stations;
- Goals of MMR operations:
  - Enhance coverage, throughput and system capacity of cellular networks;

Overview of MMR cellular networks

- Key items required:
  - 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;
- Necessary to provide enhancements to the PHY and MAC layers;
  - OFDMA PHY layer is the most appropriate for relaying operations;
  - Enhance the PHY frame structure;
  - Enhance the MAC layer by adding new protocols for the Relay;
  - Adapt/enhance Mobility/Handover procedures;
- Support for QoS is required;
  - WiMAX systems provides support for QoS; this feature has to be ensured for 802.1j MMR systems

Overview of MMR networks

- Licensed frequency bands have to be defined for operation of relay stations;
- Subscriber station specifications do not have to be changed.
  - Condition required to keep backward compatibility with previous standards and SS (Subscriber Stations without MMR capabilities);
  - In the case of WiMAX systems has to be kept the compatibility between the 802.16j and 802.16e standards.

Overview of MMR networks

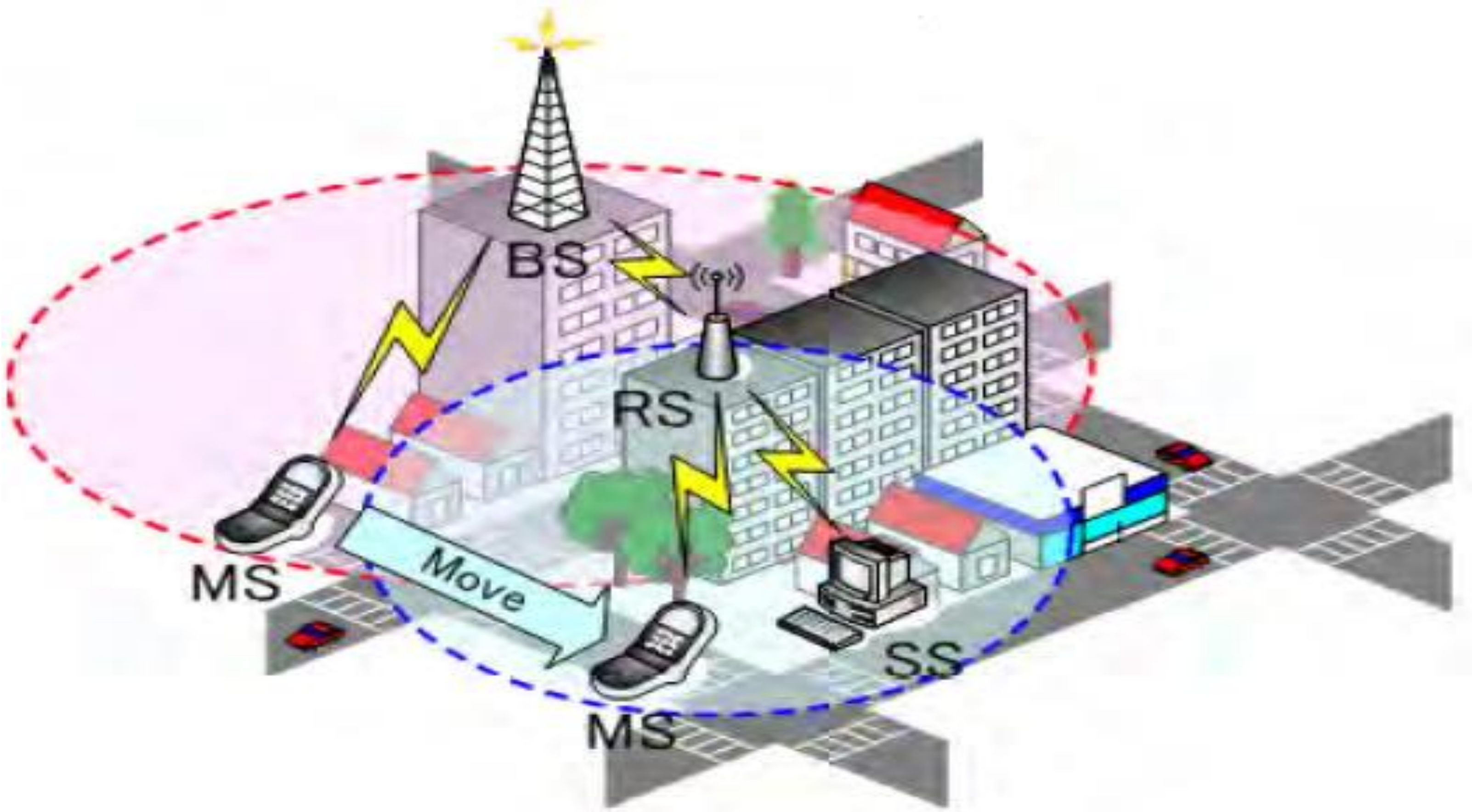
- Definitions characteristic to MMR networks:
  - MMR-base station (MMR-BS):
    - A base station that is compliant with the previous amendments and is able to communicate with MMR stations
    - In the case of the WiMAX standard a MMR-BS has to be compliant with the IEEE Standard 802.16e and with the IEEE 802.16j amendments
  - Mobile multihop relay (MMR):
    - The system function that enables mobile stations to communicate with a base station through intermediate relay stations.

Overview of MMR networks

- Definitions characteristic to MMR networks:
  - 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.

Overview of MMR networks

- Basic MMR operations; the components of the MMR cellular systems



Motivations for MMR
The MMR system architecture.

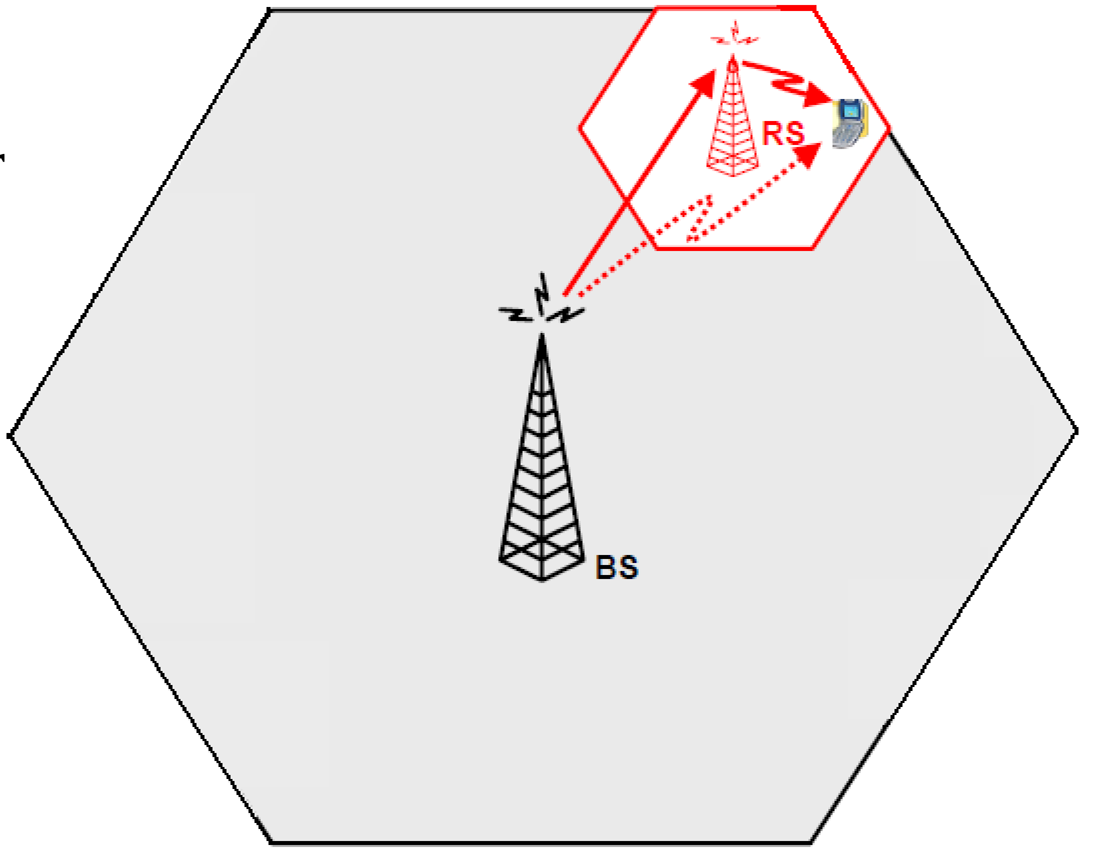
- Realities of Current Cellular Deployments:
  - Current deployments suffer from …
    - Limited spectrum and/or insufficient wire-line capacity;
    - Low SINR at cell edge;
    - Coverage holes due to shadowing;
    - Out-of-range clusters of users;
    - Non-uniformly distributed traffic load (e.g. hot spots).

Motivations for MMR
The MMR system architecture.

- Reducing cell size improves conditions, but there are several issues related to:
  - 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;

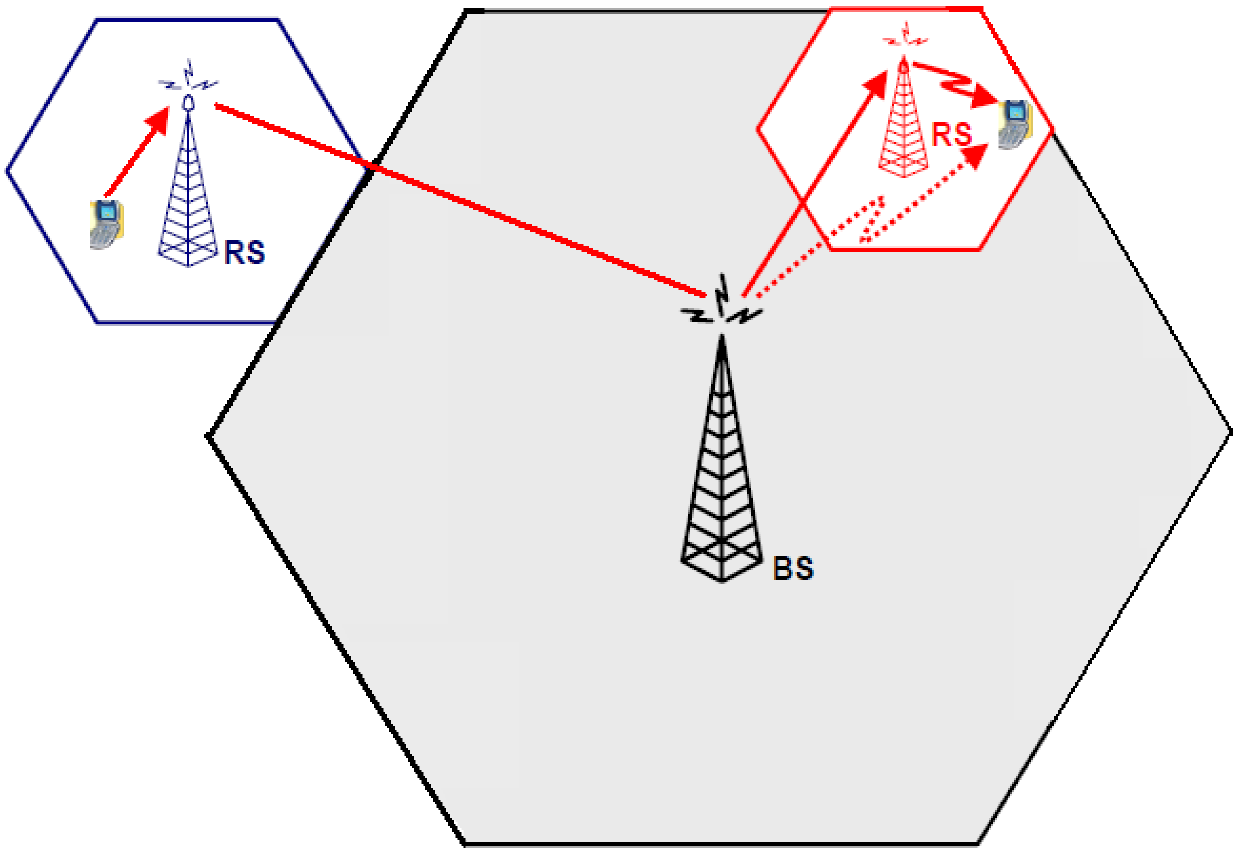
Motivations for MMR
The MMR system architecture.

- MMR ensures the replacement of low rate, unreliable links with higher rate and more reliable links through RS;
- multiple high rate, reliable links could be provided;



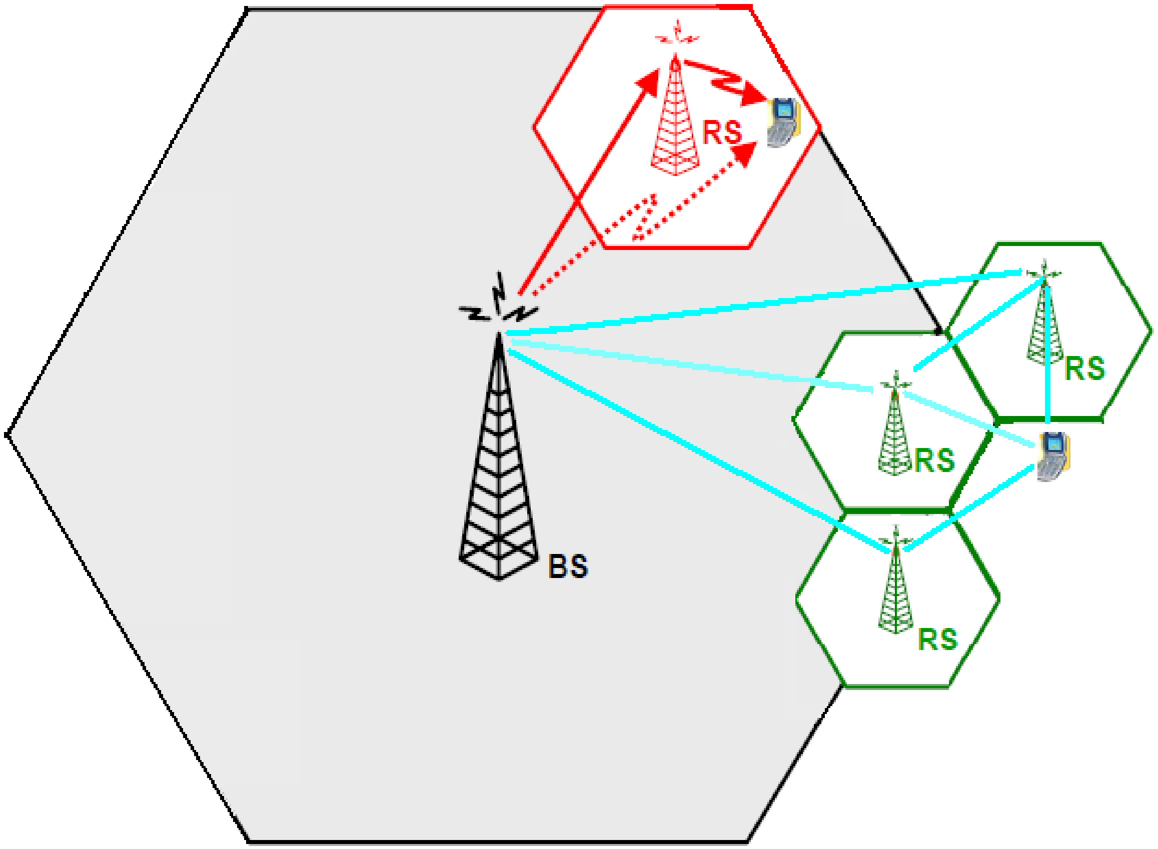
Motivations for MMR
The MMR system architecture.

- **Coverage extension:**
- Coverage extension to isolated area;
- Coverage extension at cell edge;
- Dealing with coverage holes;
- Coverage inside buildings;
- Coverage of valleys between buildings;
- Dealing with shadow of buildings;
- Providing communication in underground transport systems;



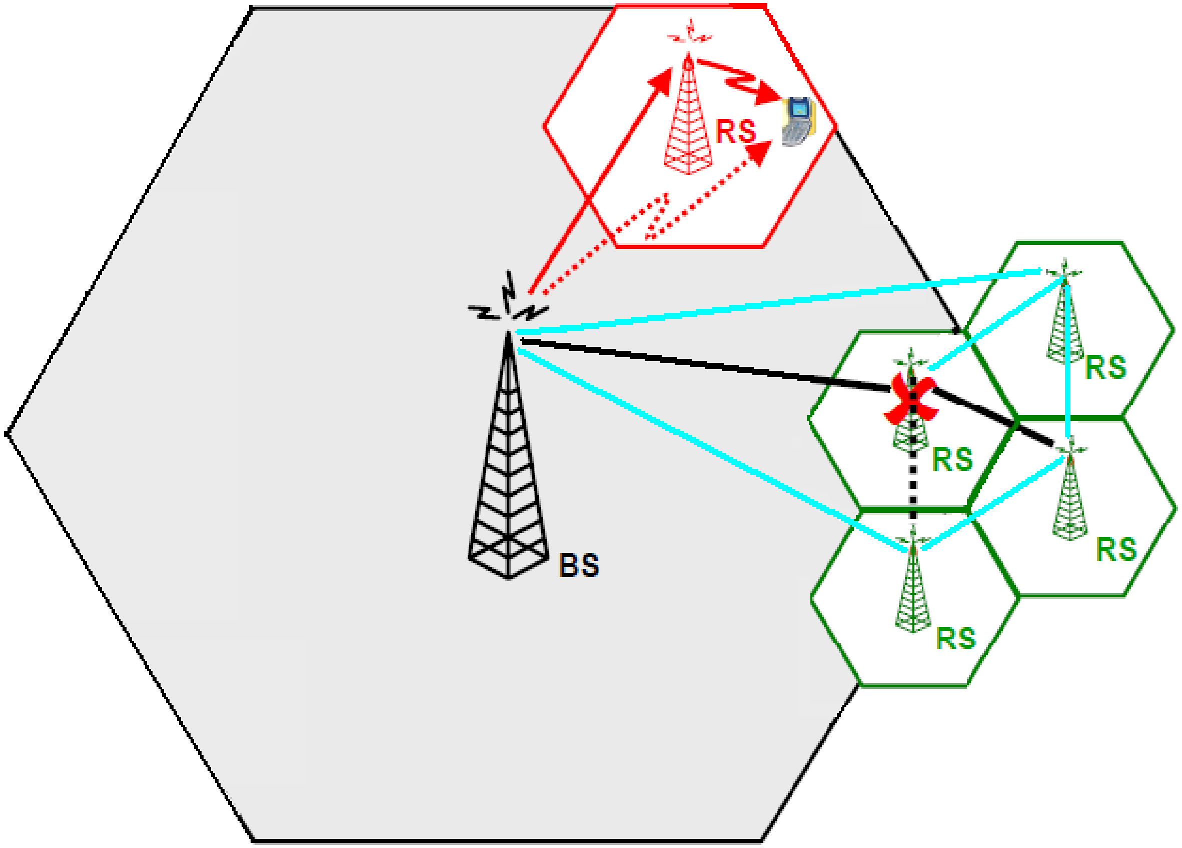
Motivations for MMR
The MMR system architecture.

- MMR transmissions could provide load sharing among RSs;
  - Important especially in coverage extension;



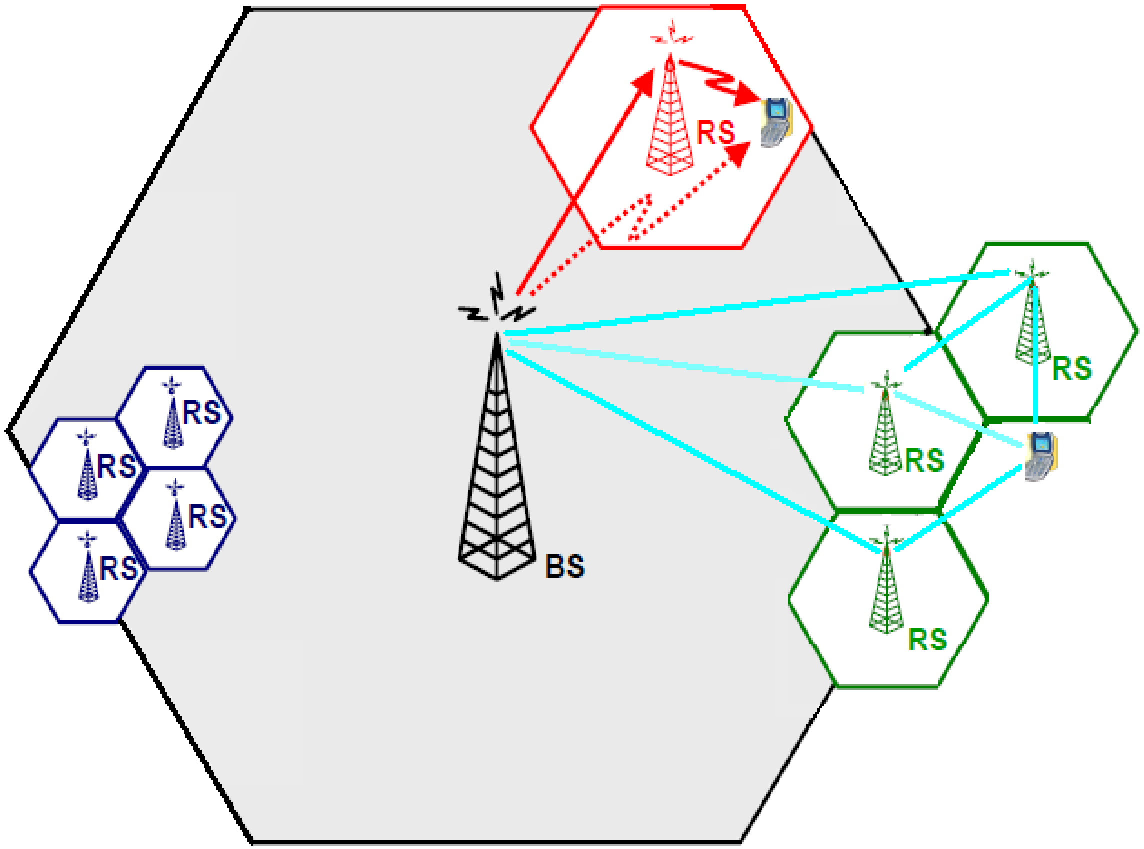
Motivations for MMR
The MMR system architecture.

- MMR transmissions could provide fault tolerance via multi-path redundancy;
  - Important especially in coverage extension;



Motivations for MMR
The MMR system architecture.

- The use of relay stations could provide complementarily:
  - Spectrally efficient architectures;
  - Good spatial frequency reuse;



Motivations for MMR
The MMR system architecture.

- Economic Benefits of MMR:
  - Lower Capital Expenditures (CapEx) and Operational Expenditures (OpEx)
    - MMR provide wireless backhaul;
    - Better trunking efficiency at aggregate points;
    - Lower site acquisition costs;
    - Less costly antenna structure for RS;
    - Lower cost and complexity of RS;
    - Faster deployment.
  - Improved ROI (Return of Investment)
    - Relay augmented network could provide higher ARPU (Average Revenue per User) through higher grades of service at lower overall incremental cost;

Motivations for MMR
The MMR system architecture.

- Case study for the WiMAX system:
  - 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 operations;
      - High spectral efficiency due to reuse, scheduling, 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;

Motivations for MMR
The MMR system architecture.

- 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;
      - Conventional WiMAX cell structure splits aggressively due to high traffic demand;

Motivations for MMR
The MMR system architecture.

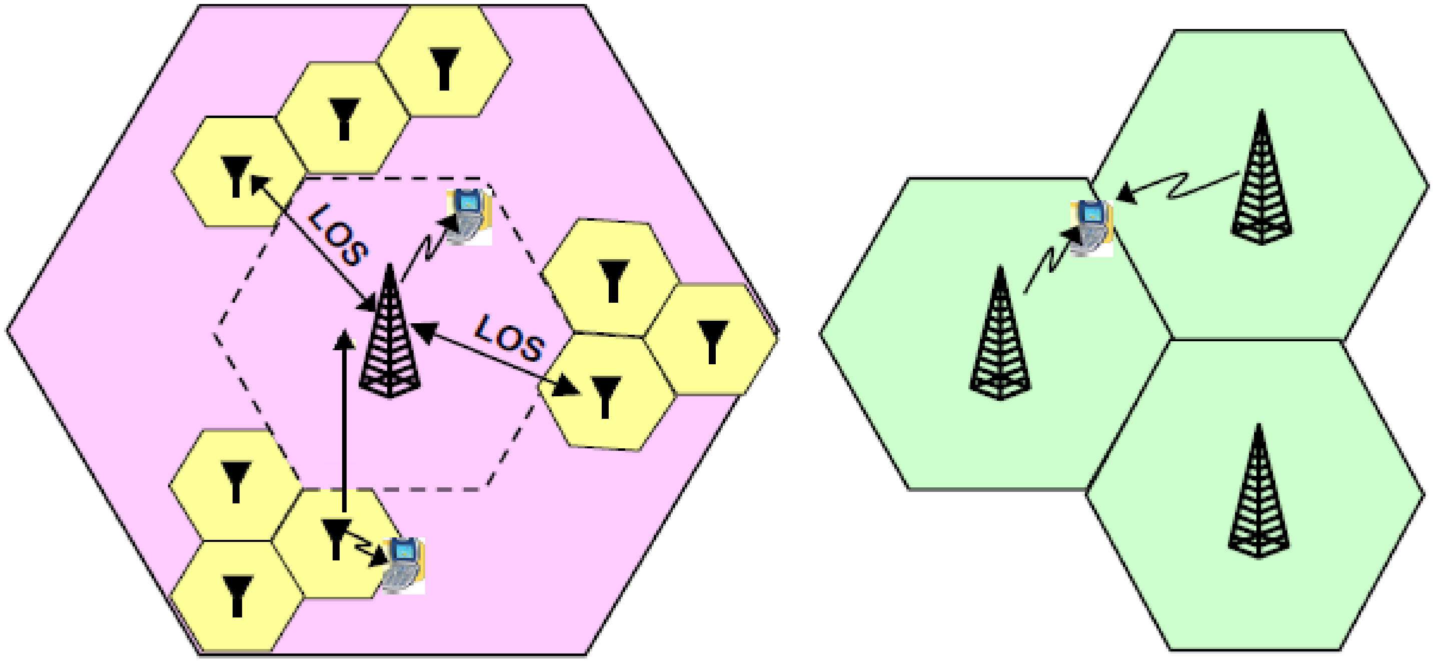
- Light Traffic, Urban/Suburban/Rural Environment
  - Range limited;
  - Traffic load based on mix of current customer demand and varying customer densities;
  - Deployments:
    - MMR-BS cell structure dimensioned for min 3.7dB SNR at cell edge;
    - Conventional WiMAX cell structure splits modestly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

Motivations for MMR
The MMR system architecture.

- **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;
  - Conclusions:
    - 802.16 MMR achieves c*ost-efficient coverage*, *capacity*, *and QoS;*

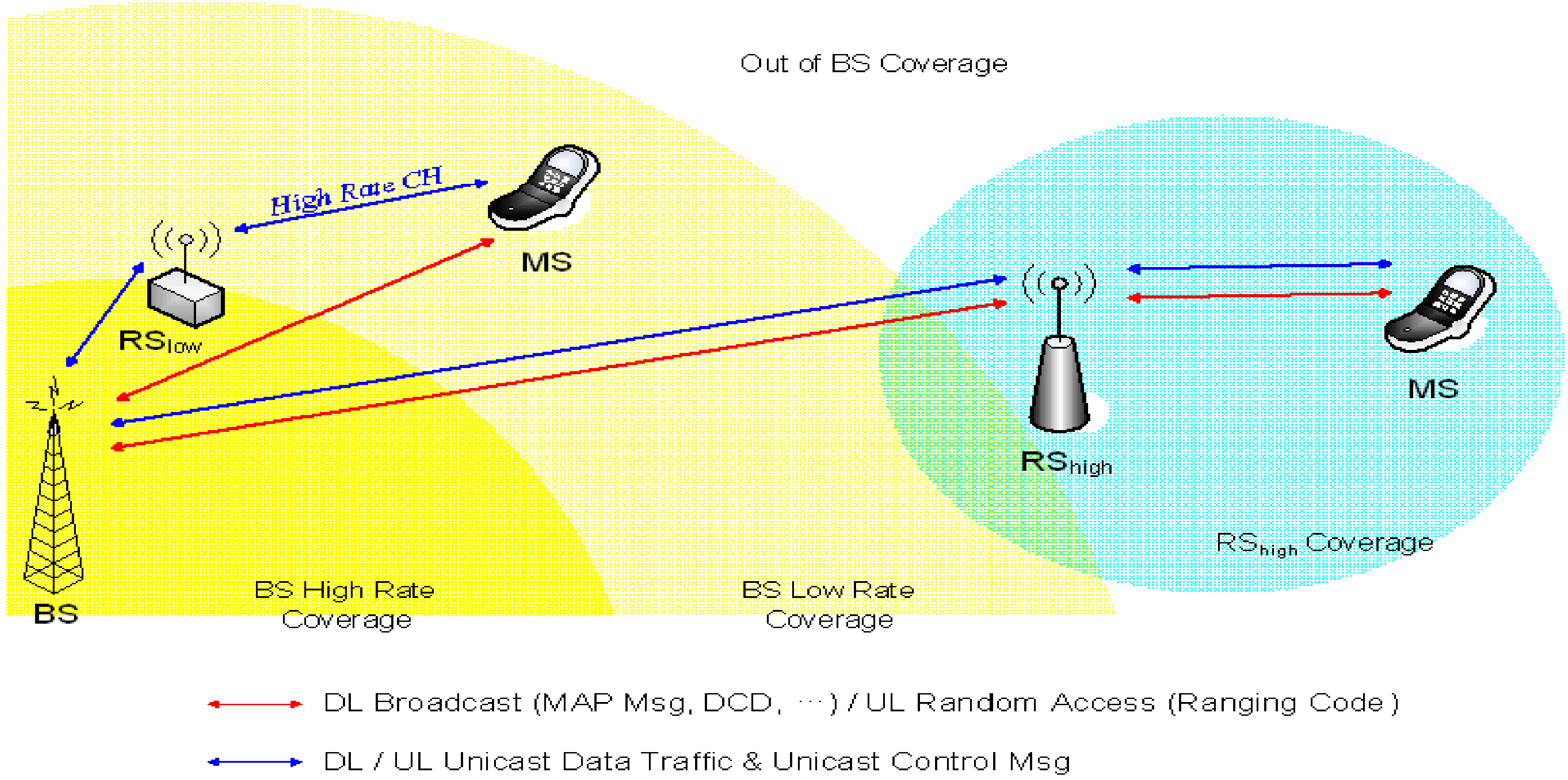
Motivations for MMR
The MMR system architecture.

- The architecture of the MMR cellular systems allows to define separate coverage areas for the relay stations;
  - The same radio resources are used in these areas;
  - These areas act as microcells inside the cell;
  - A LOS coverage area can be defined for the BS;
- The cell size of the MMR-BS can be extended – it is decreased the number of handover operations;



Motivations for MMR
The MMR system architecture.

- Details related to the relaying operations in coverage extension mode;
- Coverage areas which characterizes the cell of an MMR system;



Technical Challenges/Requirements

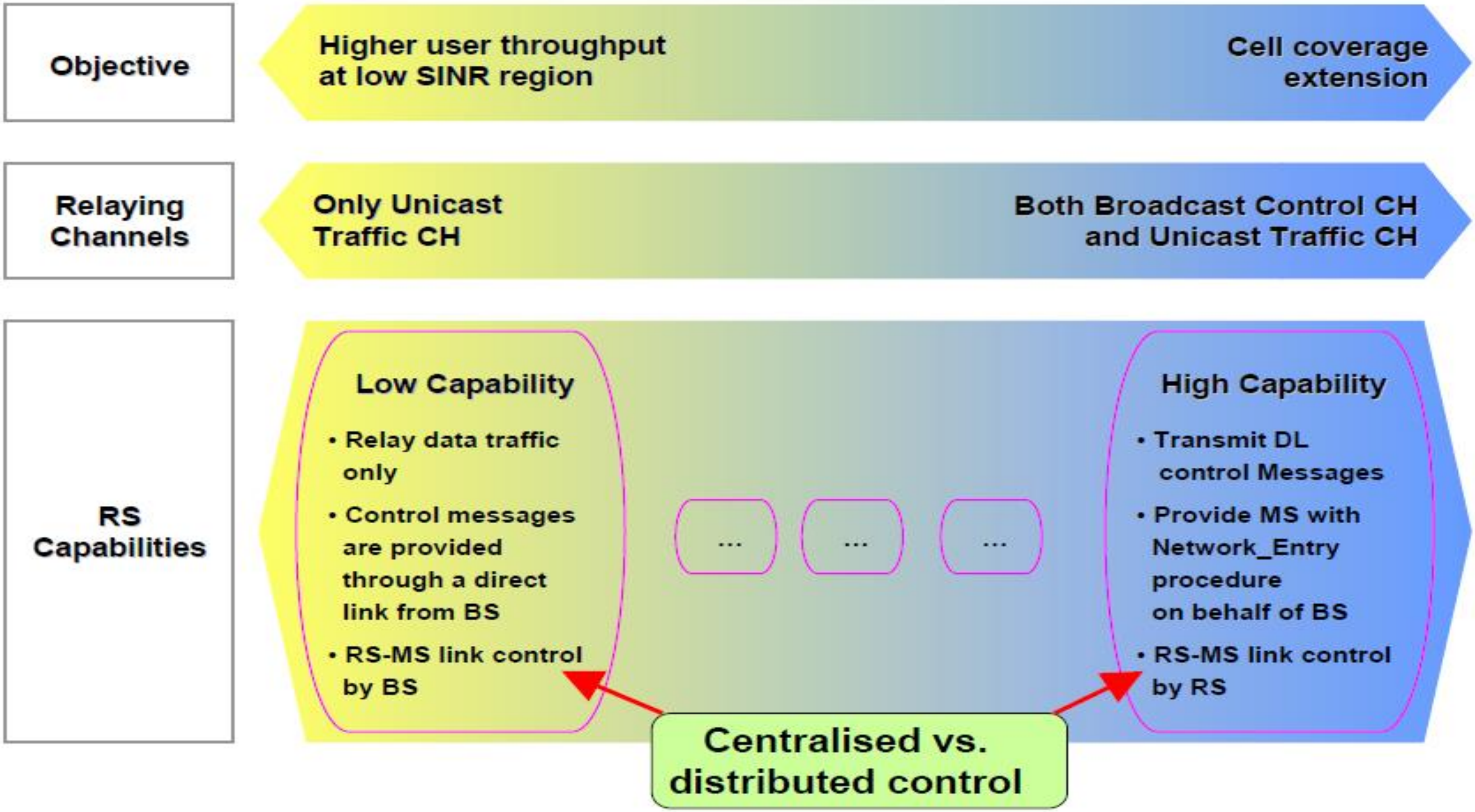
- Routing:
  - Appropriate combination of centralized and distributed control;
  - Supported routing topologies: hierarchical (tree) versus multipath redundancy;
- Scheduling, Radio resource management, Power control:
  - Appropriate combination of centralized and distributed control;
- Call admission and traffic shaping policies;
- Transport layer protocols for multi-hop networks;
- QoS provisiong by:
  - 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;

Technical Challenges/Requirements

- Potential RS types and required capabilities;

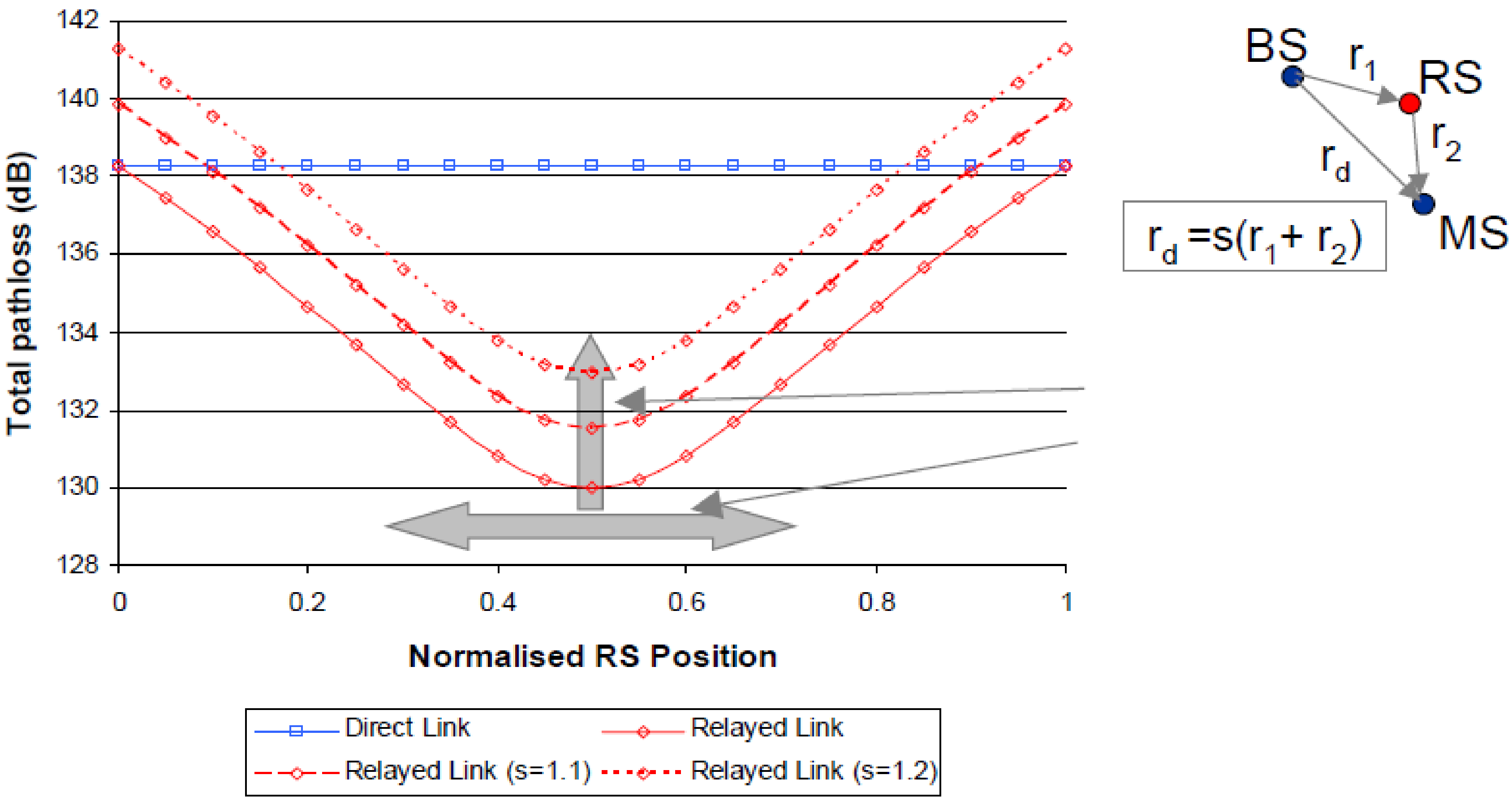


MMR performance. Technical aspects

- It is possible to demonstrate using even a basic theoretical analysis that multihop techniques provides a link budget gain; this gain can be used to:
  - Improvement in range;
  - Improvement in throughput;
  - Reduction in transmit power.
- Some general conclusions:
  - For no increase in total transmit power can be ensured:
    - Range extension for an imposed RSS (Received Signal Strength);
    - Improvement in RSS at a particular point.
  - Or can be ensured the reduction in transmit power to provide same RSS:
    - Reduction in the level of interference experienced.
  - The obtained gain depends on:
    - RS positioning;
    - Propagation properties;
    - Transmit power setting.

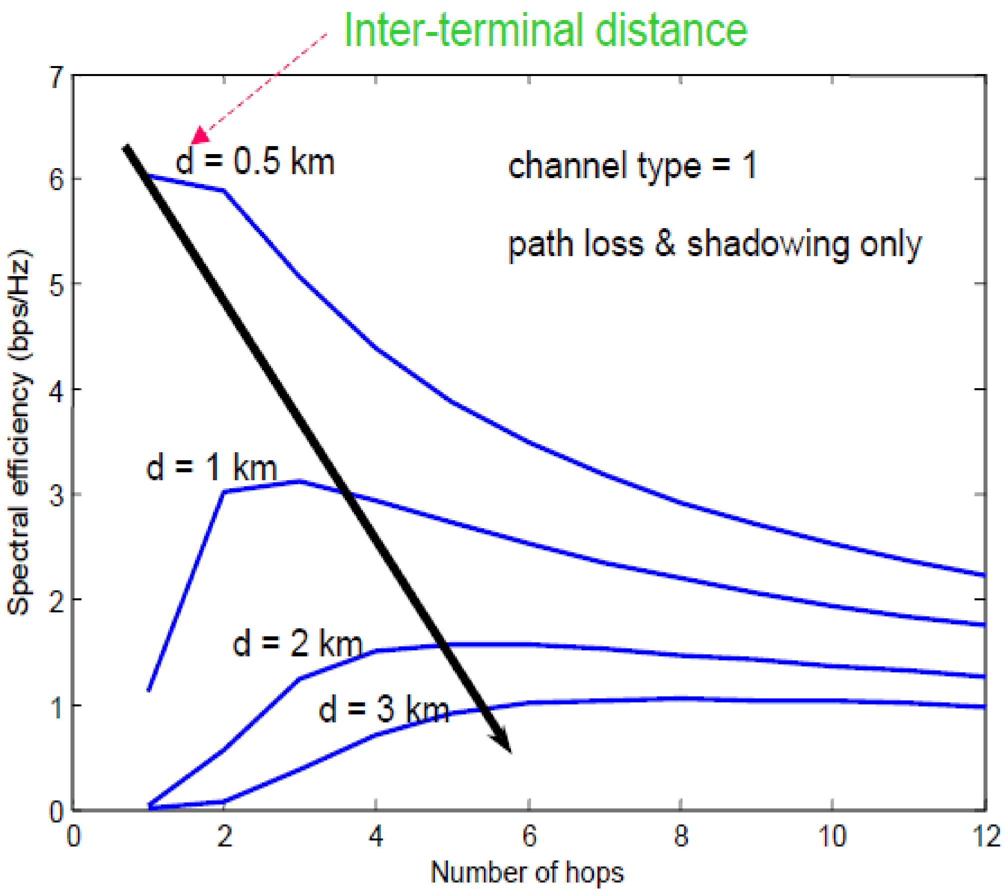
MMR performance. Technical aspects

- Effects of the relay position in a simple 2-hop case:



MMR performance. Technical aspects

- RS helps to improve significantly the spectral efficiency;
  - Improvements are strongly related to the distances between consecutive terminals - SS, RS and BS;
  - The figure provides the spectral efficiency for a multihop system with all terminals located on the same line and with the same distance between them;



MMR performance.
Technical aspects

- RS reduces outage probability, increases system reliability and provides diversity;
- MMR with no SS upgrades loses little in performance over MMR with SS upgrades;
- Two hop system outperforms the single hop system in coverage reliability by more than 3dB, but:
  - However additional radio resources are used for the transmission from a relay station;
  - Radio resource management will be a key study item in future.

MMR performance. Technical aspects

- Some significant performance values for a 2-hop fixed relay MMR system:
  - downlink transmission:
  - Received signal quality and is improved by Relay:
    - Improvement on average on received signal quality>20dB;
    - Throughput enhancement: up to 116.41% ;
  - uplink transmission:
  - MS transmit power is saved by Relay:
    - Average MS transmit power saved: ~ 10dB;
    - Throughput Enhancement: up to 41.66%;

Final conclusions

- 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 realization of the potential gain:
  - End to end QoS management (throughput & latency);
- Simulation results show that MMR could provide:
  - Improved CINR coverage and improved spectral efficiency;
  - Downlink and uplink cell throughput enhancement;
  - Reduced MS transmit power.