PMP Tree and Hybrid PMP-Mesh for Multi-Hop Relay Networks

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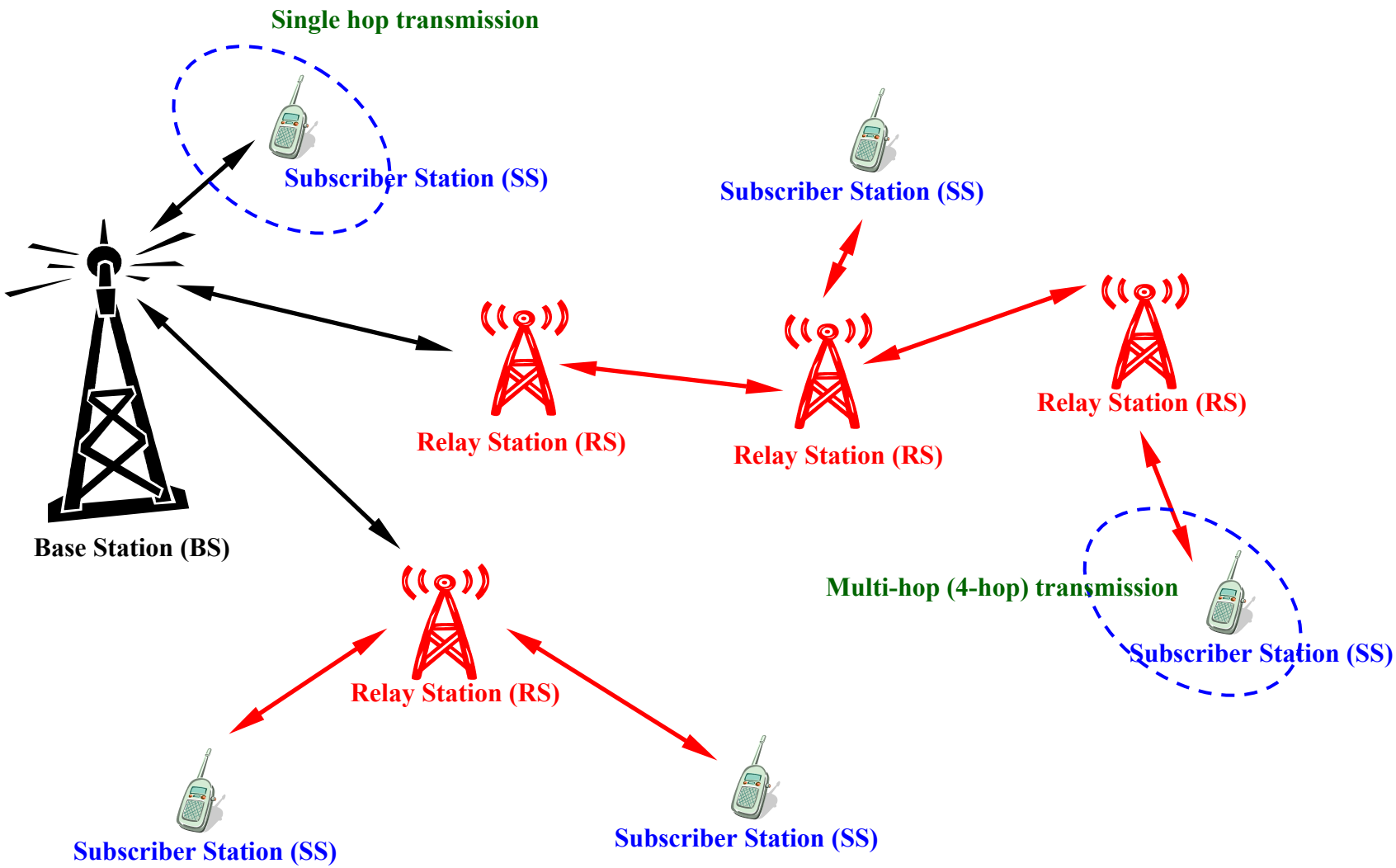
Purpose:

To propose 1 solution for the case of only 2 hops between BS and SS.
To propose 2 solutions for the case of more than 2 hops between BS and SS.

Terminology:



SS can be either mobile or static.

Usage Scenarios (1/3):

- Increase network capacity during a temporary event.
  - Huge group of people may gather at a certain area for a special event. If the area is far from the BS and QPSK has to be used, bandwidth efficiency will be low. The BS capacity may not be enough.
  - We can **rapidly** deploy a RS which can communicate with the SS efficiently. At same time, RS can also communicate with BS efficiently via better antenna.

Normal day: Quiet street.

New Year Eve: Crowded with party goers

Usage Scenarios (2/3):

- Resume communications during disaster reconstruction.
  - In case of disaster where communication infrastructure is destroyed, we can **rapidly** deploy RS which can connect to the nearest functioning BS.
  - Therefore, powerful and high-speed wireless links can be used to resume Internet connections during the reconstruction.

Usage Scenarios (3/3):

- Extend network coverage.
  - Due to **irregular** shape of the residential area, SS could be too far from the nearby BS for an efficient communication. However, it is also not economic to install a new BS due to small population.
  - In rural area, people live in villages. In each villages, there are several hundreds of people and the distance between villages can be several kilometers. Most of the time, people will stay in the village or nearby.
  - Install an additional RS may lead to a much better coverage and efficiency at a low cost in a short time.

Technical Requirements:

- Capability of RS:
  - Enhance throughput & extend coverage.
  - Simple implementation, low cost and easy deployment.
  - Compatible with 802.16e (OFDMA).
  - For end-to-end QoS, RS which is between BS & SS must also be QoS capable.
  - Self-organization for mobile RS. This could be a costly feature for fixed RS.
  - No just amplify-and-forward (AF) or decode-and-forward (DF).
  - Has intelligence to schedule transmission for cooperative communications.

- Difference from BS:
  - RS has shorter radio range and lower transmission power.
  - RS handles less traffic.

How Many Hops?

- Options:
  - Support up to 2 hops between BS and SS.
  - Support more than 2 hops between BS and SS.

- System can be significantly more complex when hop count is larger than 2. But, what is the advantage of more than 2 hops?

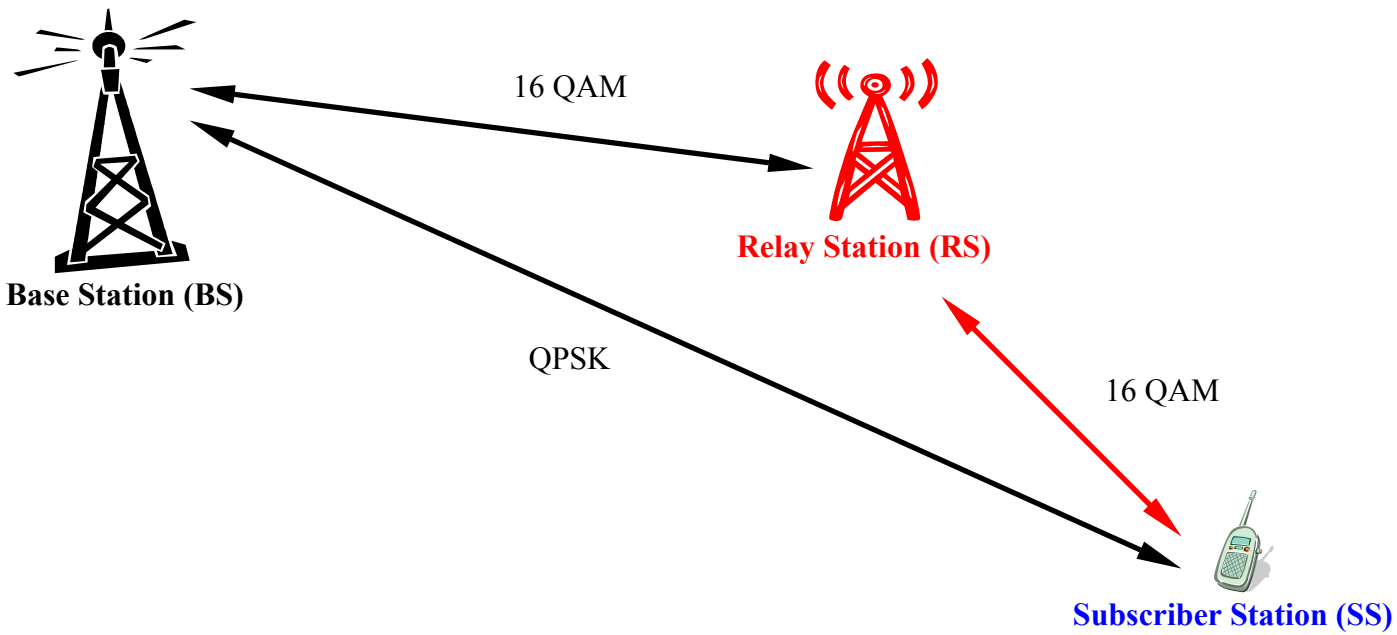
- It is an overkill to apply a general solution to a 2-hop network.

- Propose 1 solution for up to 2 hops case.

- Propose 2 solutions for the case of more than 2 hops.

A Simple Solution for up to 2 Hops

- Communication Scenario
  - PMP mode
  - Control packets: SS←→BS
  - Data packets: SS←→RS←→BS



Up Link:

- SS sends directly bandwidth request to BS.
  - Request to transmit *L* bits in one or several frame.
- BS knows there is a RS nearby the SS and thus, allocates bandwidth as follows:

$$nm\_slots\_1 = \left\lceil \frac{L}{B_1} \right\rceil, \qquad nm\_slots\_2 = \left\lceil \frac{L}{B_2} \right\rceil \qquad (1)$$

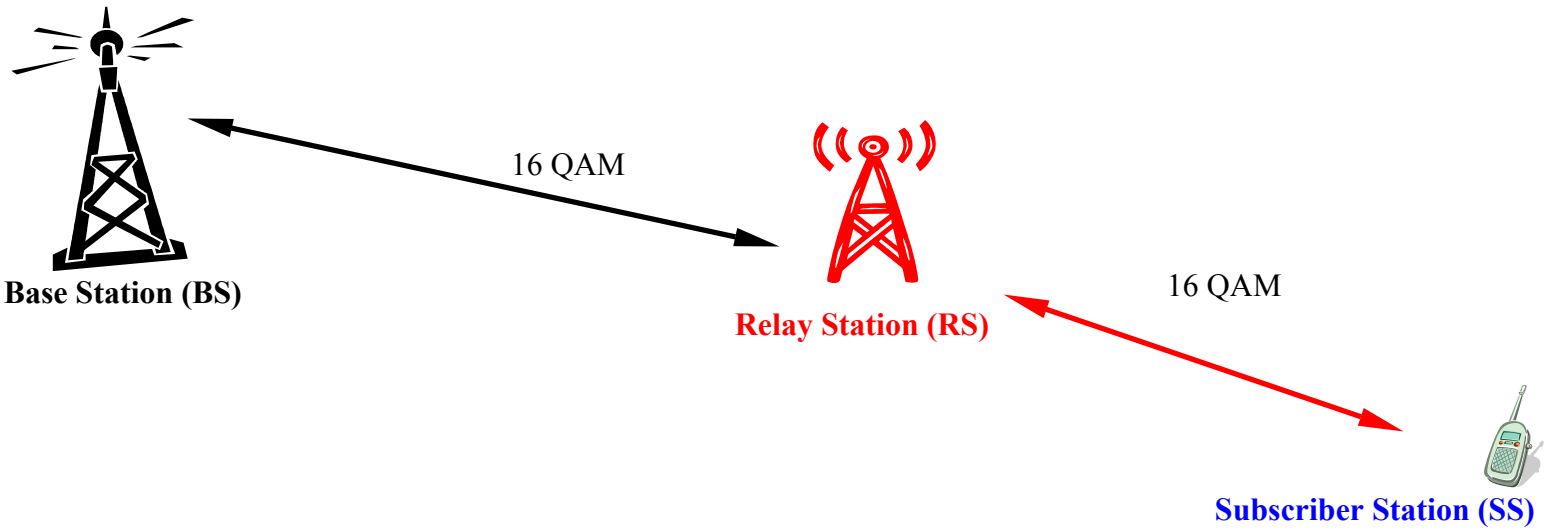
  - B1: the transmission rate of link SS→RS.
  - B2: the transmission rate of link RS→BS.
- BS broadcasts in the Up Link Map (UL-MAP) the bandwidth allocations to both SS (nm_slots_1) and BS (nm_slots_2).
- Data packets are transmitted with the allocated bandwidth via RS in up link sub-frame. (SS→RS→BS)

Down Link:

- BS wants to send *L* bits data to SS via RS.
- BS calculates the required bandwidth using the same equation (1).
- BS broadcasts the bandwidth allocation in the Down Link Map (DL-MAP).
- BS transmits the data packet to RS.
- RS transmits the data packet to SS.

Coverage Extension (1/2)

- SS is out of the transmission range of the BS.
- RS relays both the control message and data packets between BS and SS.

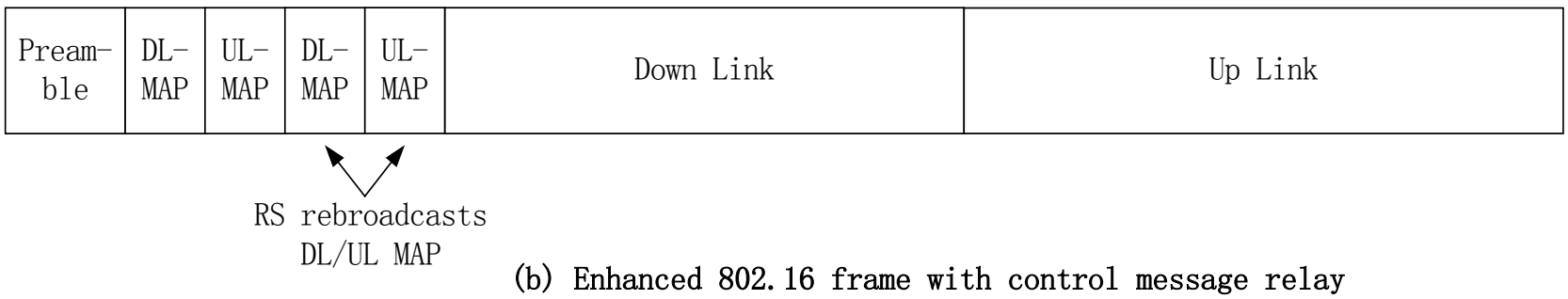


- Bandwidth Request is first send to RS.
- RS further sends the bandwidth request to BS.
- BS should know the modulation scheme used between the RS and SS.

Coverage Extension (2/2)

- BS allocates the bandwidth for the transmission according to the same equation (1).
- RS rebroadcasts the DL/UL-MAP after BS finishes the normal DL/UL-MAP at the beginning of down link sub-frame.
- BS should not transmit data when RS rebroadcast DL/UL-MAP.

(a) Normal 802.16 frame



(b) Enhanced 802.16 frame with control message relay

2 solutions for more than 2 hops:

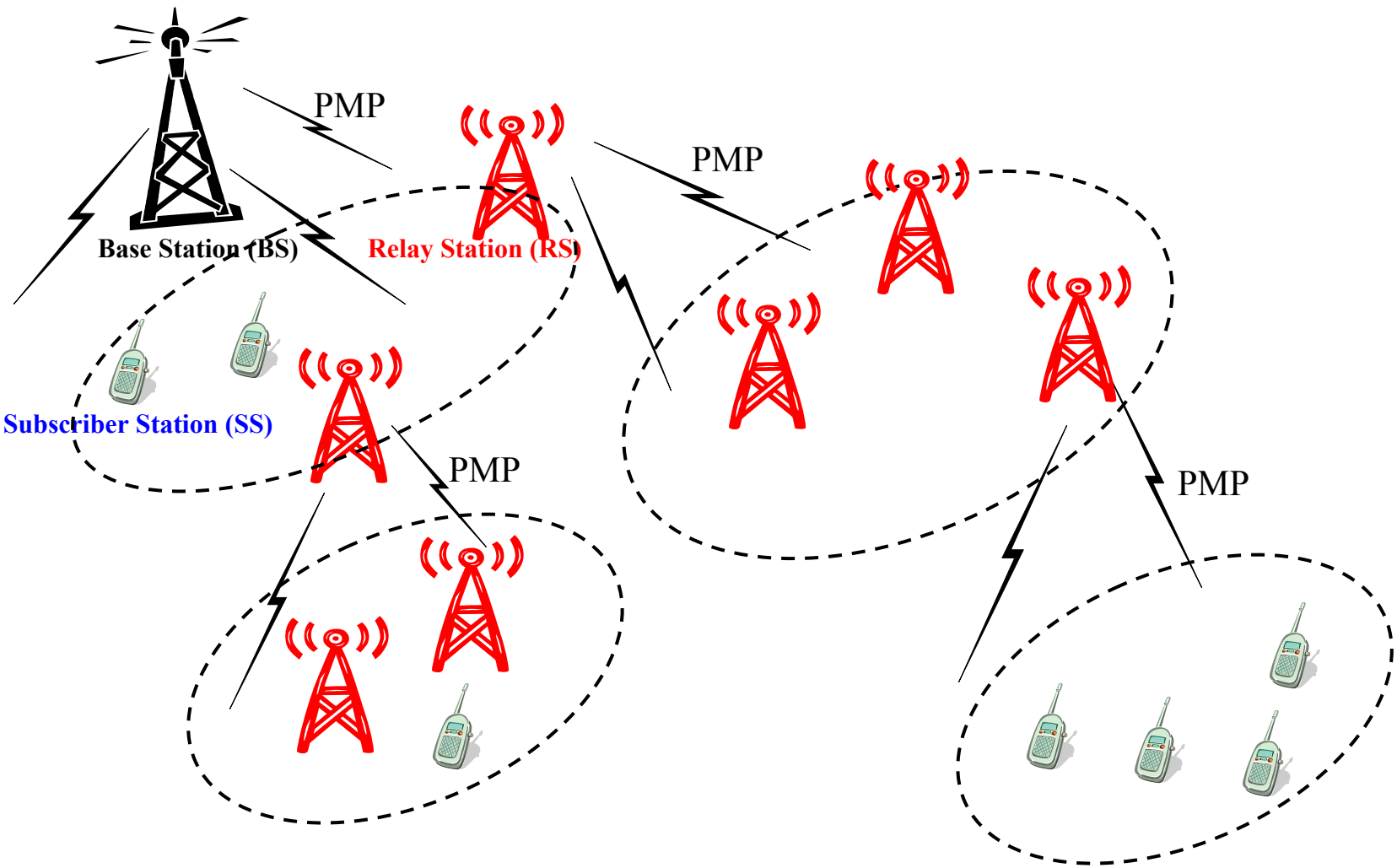
- There are two possible architectures:
  - A tree of PMP networks between BS and SS
  - A hybrid PMP-Mesh architecture with a mesh network between BS and SS.

- **PMP Tree:**
  - **Pros:**
    - Better efficiency and control when the depth of tree is small.
    - No hidden node and exposed node problem.
  - **Cons:**
    - Single point of failure.

- **Hybrid PMP-Mesh:**
  - **Pros:**
    - Robust. No single point of failure.
    - More flexible in allocation of resources.
  - **Cons:**
    - More control messages required. Less efficient.
    - Cost may be high.

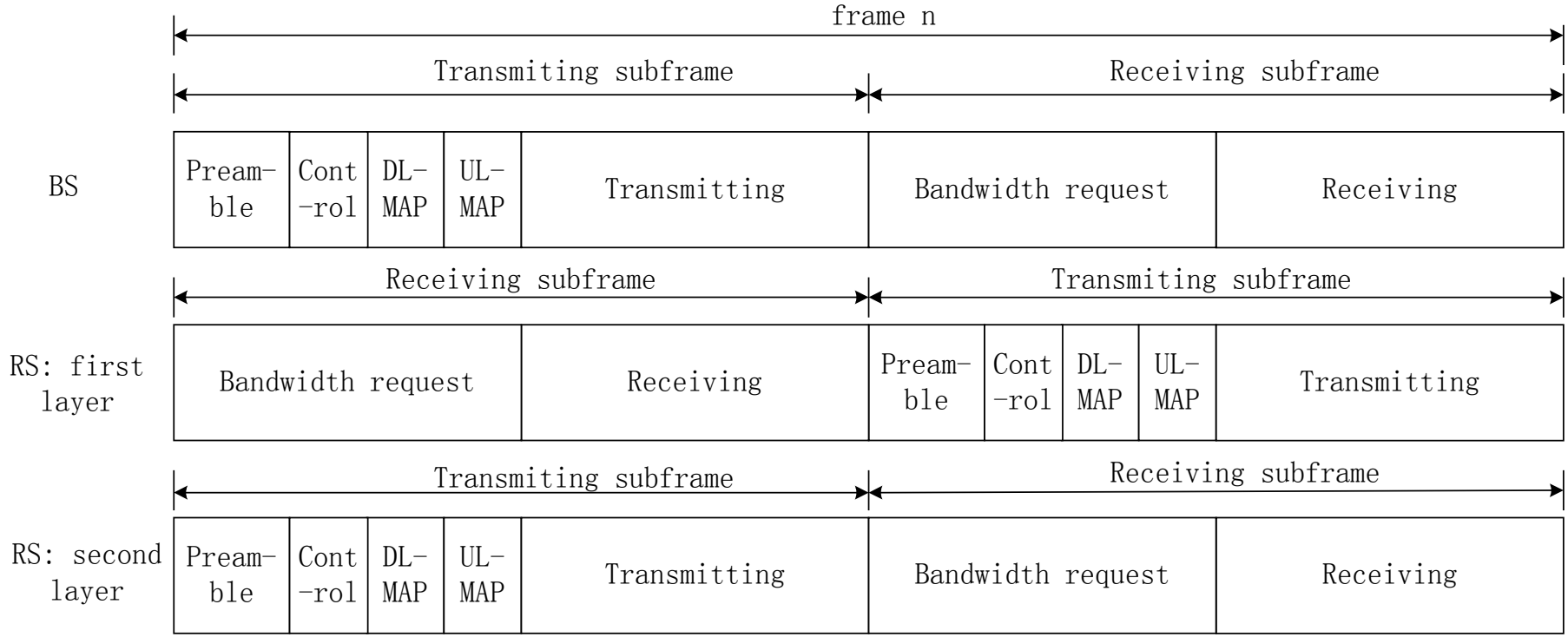
- **Consideration:** Use PMP Tree when the number of tree depth is small, else use the Hybrid PMP-Mesh architecture.

PMP Tree:


PMP
PMP
Base Station (BS)
Relay Station (RS)
Subscriber Station (SS)
PMP
PMP

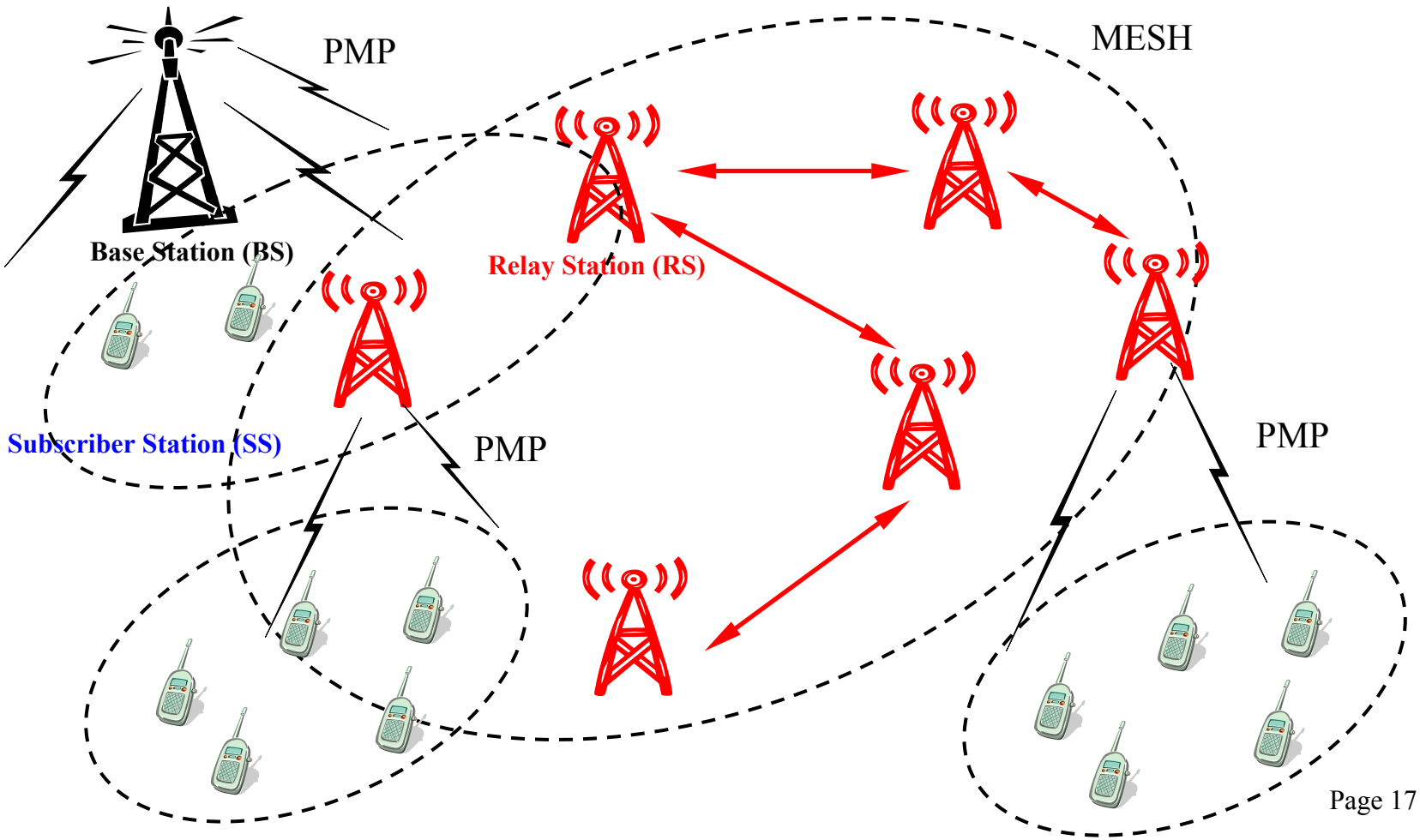
An Example Solution for PMP Tree

- Half-frame shifting between BS and RS or RS and Child RS.
- Different channel in communication.
  - Communications with parents use channel set assigned to parents.
  - Communications with children (RS or SS) use channel set assigned to this RS.



Hybrid PMP-Mesh:

- BS and RS support both Mesh and PMP.
- Peer-to-peer communications among RS.
- SS: support PMP only.



Advantages of the hybrid PMP-MESH:

- Mesh is flexible.
  - Suitable for robust multi-hop communications.
  - Easy for the network adapt to topology changing, especially for the Mobile RS deployed for temporary event and when is relay node failure.
  - Enable peer-to-peer communication between RS.

- PMP is probably more efficient in single hop communication but not in multi-hop communications when the tree depth is not small.

- With the two layer structure, the network is flexible and efficient. Also, it could be compatible to IEEE 802.16e at the interface to SS.

Evaluation Methodology:

- All proposals must be evaluated through simulations and supported by robust results.
  - NS2, OPNET, QualNet, etc.

- Performance metrics must be agreed upon.
  - Throughput, delay, utilization, etc.

Conclusion:

- It is an overkill to use an *n*-hop solution for a 2-hop relay network.
- Propose 1 solution for up to 2 hops case.
- Propose 2 solutions for the case of more than 2 hops: PMP Tree and Hybrid PMP-Mesh.
- Peer-to-peer communications among RS is not allowed in PMP Tree but Hybrid PMP-Mesh.