Evaluation of Relay Frame Structures and Recommendations for Changes

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Venue:

Session 57, Kobe, Japan **re: SDD Session 56 Cleanup**

Base Contribution:

None

Purpose:

SDD Session 56 Cleanup: Material in support of SDD comments on relay frame structure. For discussion and adoption by the TGm

Notice:

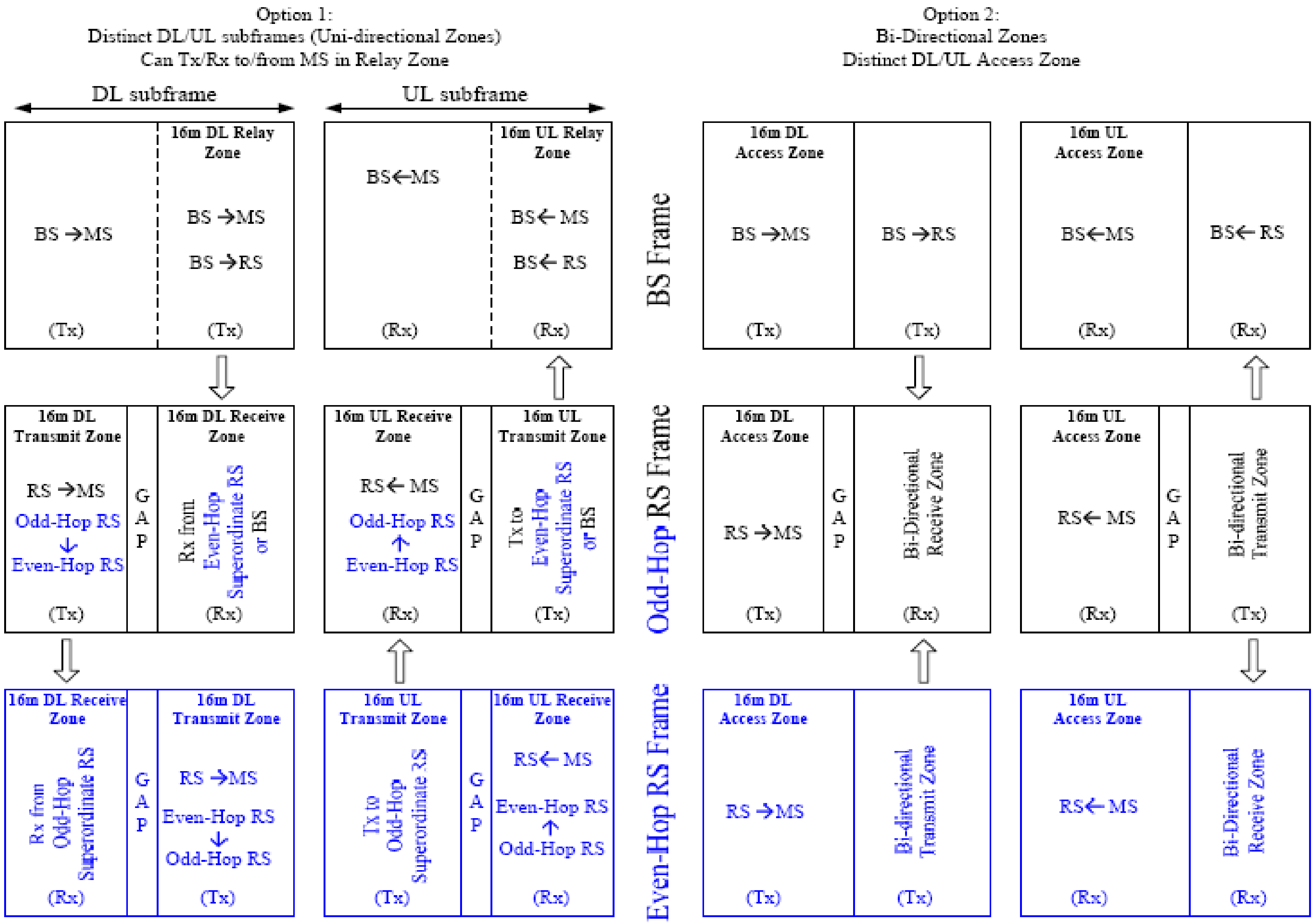
Outline

- Purpose
- Evaluation Criteria
- Evaluation Summary
- Conclusions
- Text Recommendations

Purpose

- Clause 11.4.4 of SDD specifies 2 options for relay FS; states that further study is required to select a single option
- In this contribution we:
  - summarize the analysis that we have performed to compare the two options.
  - Recommend the option which we believe should be selected
  - Propose some modifications that should be made to this option to address some of the questions that were debated during session 56.

Frame Structure Options



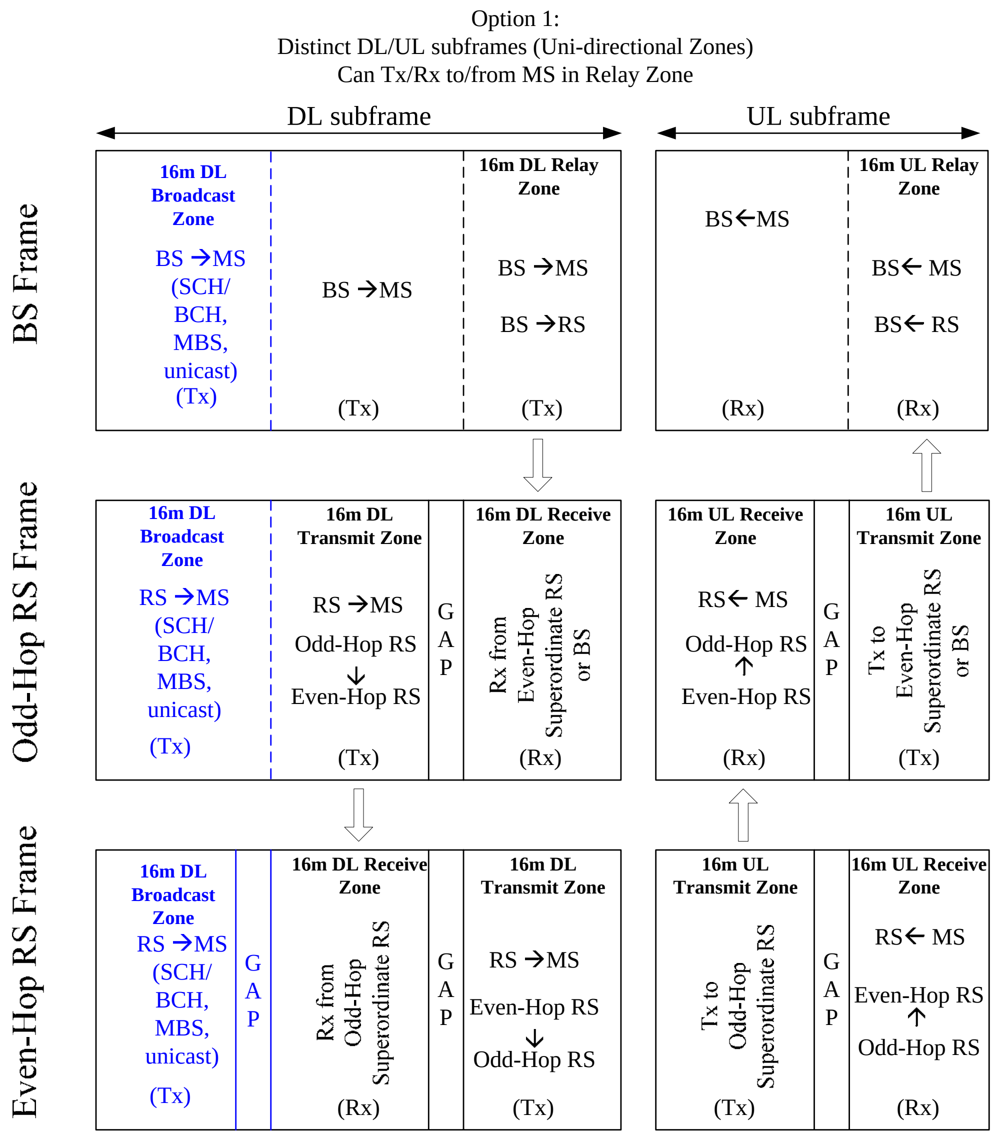
Evaluation Criteria

- Location of SCH/BCH and synchronization
- MBS Support
- Implications on Symbol Structure
- Sector throughput in DL and UL
- Switching point overhead
- DL/UL ratios
- Flexibility relative to variations in loading
- Maps and Scheduling
- Latency implications
- Support for Multi-user MIMO
- Cooperative diversity Support

SCH/BCH and MBS Considerations

- It is not clear how SCH/BCH broadcast and MBS are supported in FS Option 1 because Even hop RSs do not transmit to the MSs at the same time as the BS and Odd hop RSs in the current option 1 FS.
- We propose that an additional zone be added to the DL portion of the Option 1 FS in order to provide a common place for SCH/BCH and MBS transmissions
  - SCH/BCH and MBS are synchronized across relay and non-relay sectors
  - An additional gap is required for even hop RSs and one possible DL/UL ratio is eliminated
    - See DL/UL ratio and Switching point analysis for details

Proposed modifications to Option 1 FS to support SCH/BCH and MBS transmissions



SCH/BCH and MBS Comparison

- If we assume the modifications proposed for the Option 1 FS, SCH/BCH transmission and MBS support are the same in both Option 1 and Option 2 FS.
  - Differences in DL/UL ratios and switching point overhead are considered separately later in this contribution

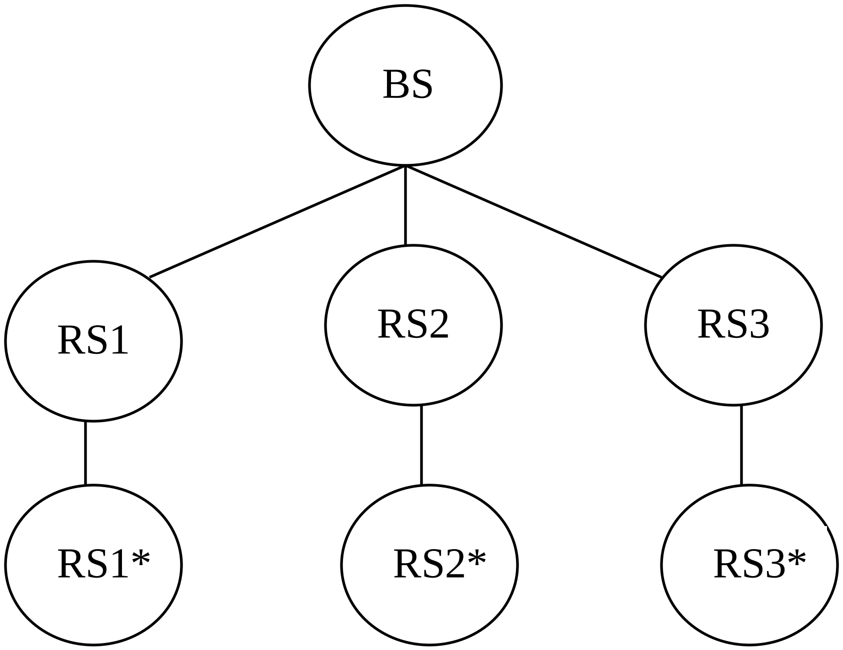
Symbol Structure Overview

- DL and UL symbol structure uses two stage approach to allocation of resources
  - First subcarriers are grouped into Physical Resource Units (PRUs) and groups of PRUs are created
  - Localized or distributed subchannels are created within each PRU group.
- DL and UL PRUs are the same size (18 subcarriers x 6 symbols)
  - One exception is UL symbol structure for FDM partitioned legacy mode
- DL and UL subchannels can co-exist within a subframe through the creation of DL and UL PRU groups
  - A special DL symbol structure would need to be defined in order to do this in the case of FDM partitioned legacy mode
- Pilot overhead
  - DL and UL localized structure: ~5.6% per stream
  - DL distributed structure: ~5.6% per stream
  - UL distributed structure: ~11% per stream

Assumptions about Symbol Structure

- FS Option 1
  - DL symbol structure for both DL zones
  - UL symbol structure for both UL zones
- FS Option 2 – two variants
  - Variant A: Partition bidir zones in frequency (two or more PRU groups)
    - One or more PRU groups for DL using DL structure
    - One or more PRU groups for UL using UL structure
    - Partition between DL and UL can be changed on a superframe boundary but not on a frame boundary
    - Partition between DL and UL must be coordinated across RSs within a tier (see next slide for an illustration)
    - A special DL symbol structure would need to be defined in order to use variant A in the case of FDM partitioned legacy mode
  - Variant B: Use UL symbol structure for both bidirectional zones
    - Partition between DL and UL can be changed on a frame boundary, but is subject to scheduling coordination and map transmission latencies
    - Additional pilot overhead is incurred for DL transmissions
    - BS must be able to transmit using the UL symbol structure
    - DL Control channels are defined assuming DL symbol structure

DL/UL Partitions in the bidir zones (FS Option 2)



BS Frame Bidir Zone

DL: BS->RS1
DL: BS->RS2
DL: BS->RS3

RS1 Frame Bidir Zone

DL: BS->RS1
UL: RS1* -> RS1
UL: RS1* -> RS1

RS2 Frame Bidir Zone

UL: RS2* -> RS2
DL: BS->RS2
UL: RS2* -> RS2

RS3 Frame Bidir Zone

UL: RS3* -> RS3
UL: RS3* -> RS3
DL: BS->RS3

Locations of DL and UL transmissions must be coordinated between RSs in a tier and their superordinate station

Comparison relative to symbol structure

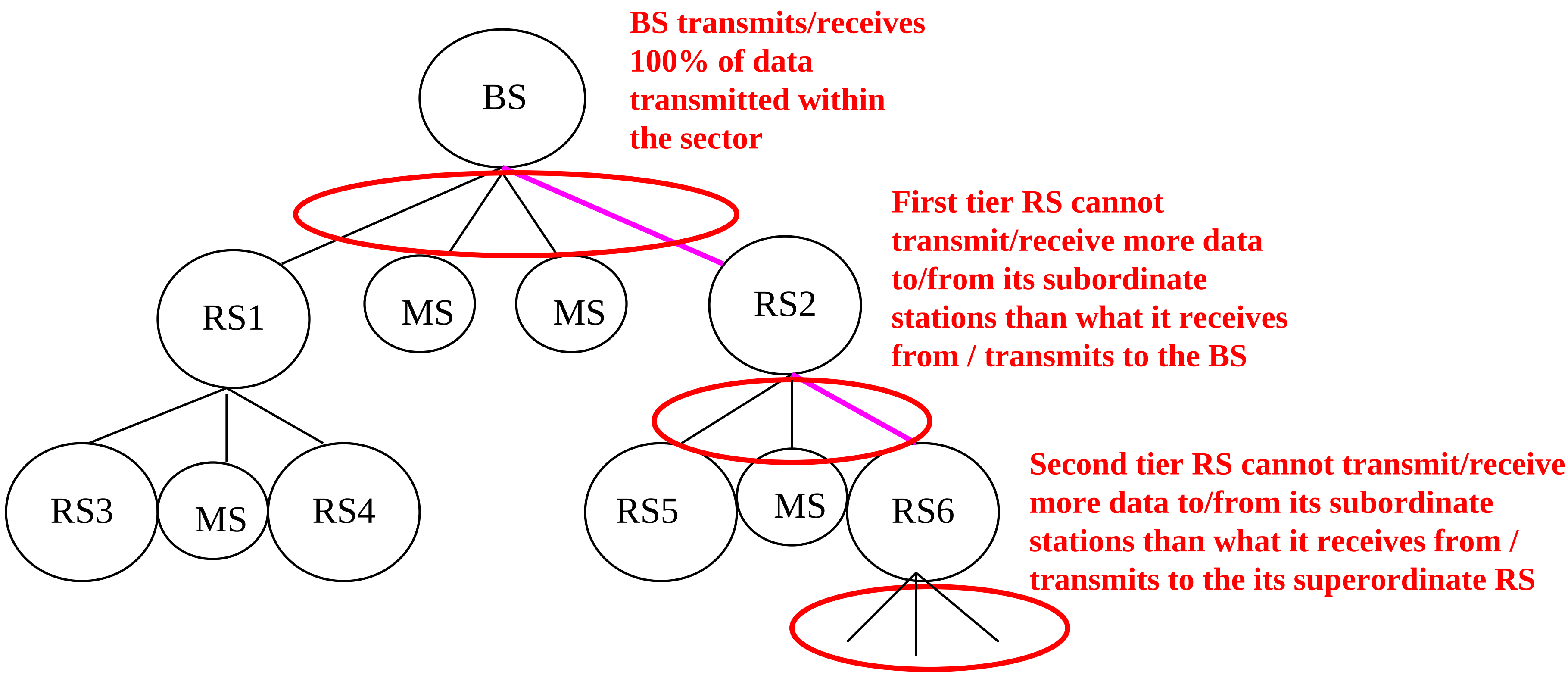
	Option-1	Option-2 Variant-A	Option-2 Variant-B
coexistence with cells without relays	yes	Additional design complexity for MS receiver - interference may be not uniform in PRU	Additional design complexity for MS receiver - interference may be not uniform in PRU
RS complexity	DL structure -TX/RX UL structure -TX/RX	DL structure –TX/RX UL structure -TX/RX	DL structure -TX UL structure -TX/RX
BS complexity	DL structure - TX UL structure - RX	DL structure - TX UL structure - RX	DL structure - TX UL structure – TX/RX
pilot overhead	small	small	Additional overhead due to UL structure used for DL
PRU design for relay link	reuse of 16m	reuse of 16m Need to define relay-specific structure for legacy mode with FDM partition	reuse of 16m

- Option 1 is better supported by the current symbol structure
- Option 2 requires a more complex symbol structure

Sector Throughput in DL and UL

- We define sector throughput to be the rate at which the BS and associated RSs transmit data to/from all MSs within the sector
  – This definition is consistent with the 16m EMD definition of sector throughput (formula 102 on page 123 of 16m EMD).
- Sector throughput depends on many factors:
  – antenna techniques
  – geographical locations of MSs and RSs
  – topology of the network and loading
  – scheduling and QoS requirements
- We compare the maximum sector throughput that can be achieved with FS Option 1 and Option 2

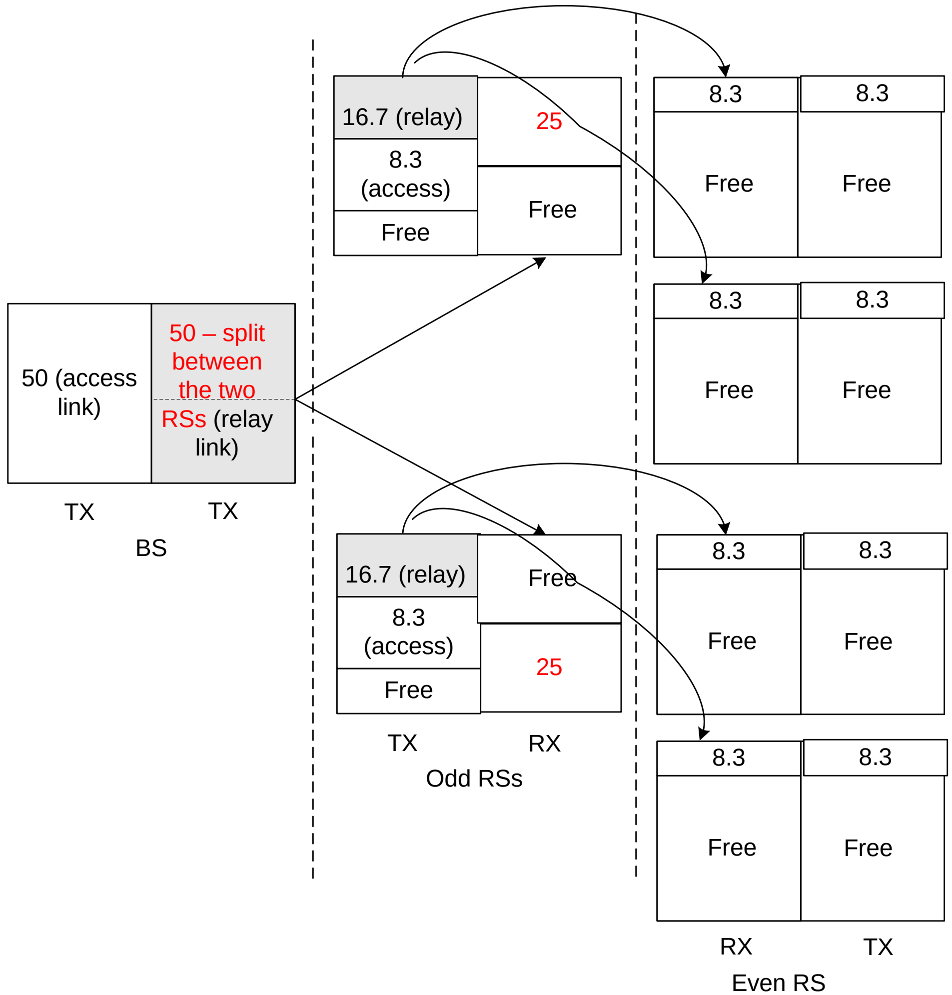
Analysis of Sector Throughput in the Relay Case



- In tree topology all data flows through the root (BS)
- From perspective of frame structure all data that flows through the sector is transmitted in the BS frame (and part of it is retransmitted in RS frames)
- Sector throughput is bounded by the BS total throughput – by the amount of data that can be transmitted within the BS frame
- RSs have less data to send so in general they will not be the bottleneck

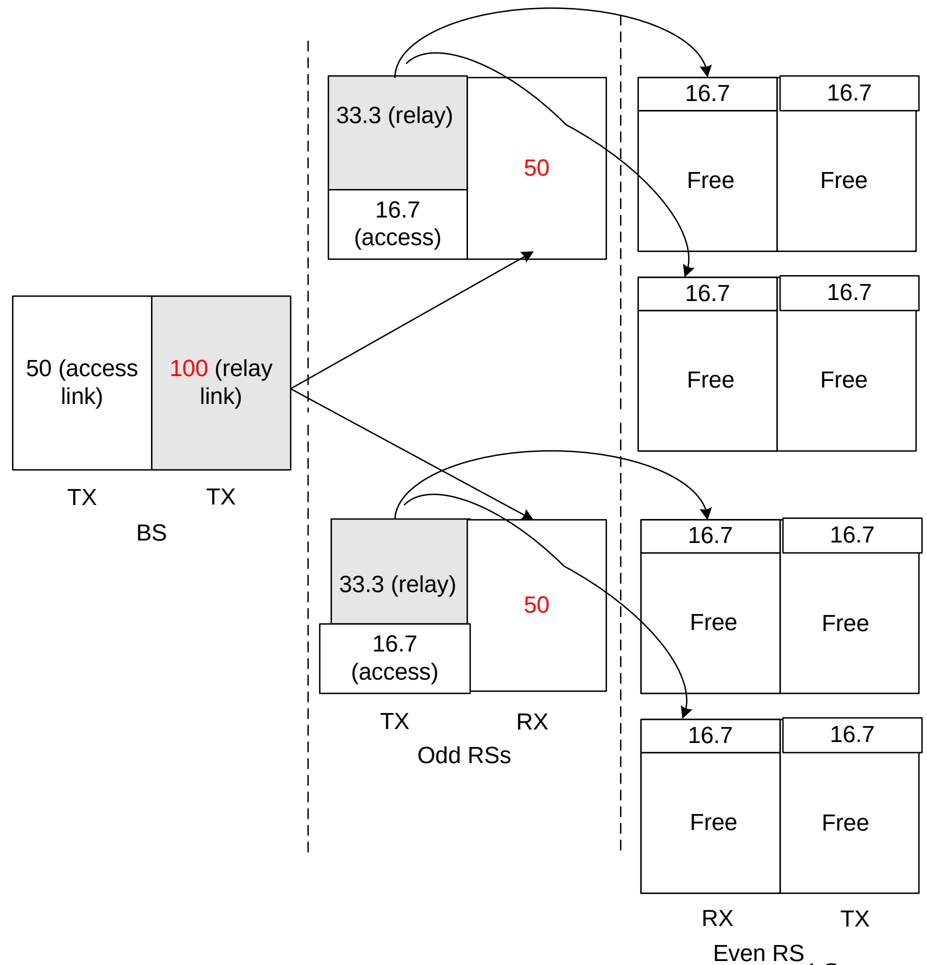
Sector Throughput in FS Option 1 DL without Spatial Multiplexing

- Consider a simple example with the following assumptions:
  - Same topology as on previous slide
  - Spectral efficiency of access and relay links is the same
  - BS serves 50% of MS traffic directly
  - Remaining 50% of MS traffic is equally divided among the 6 RSs.
- BS uses time/frequency division to divide relay zone among the two first hop RSs.
- Numbers in the zones indicate amount of throughput passing through the zone in normalized units where each unit represents 1/100 of the traffic that can be transmitted by the BS in the DL portion of the frame without spatial multiplexing
- Maximum sector throughput is 100 units per frame in this example
- Adding a third branch to the topology does not change maximum sector throughput



Sector Throughput in FS Option 1 DL with Spatial Multiplexing

- Assumptions are the same as in the previous example
- Assume that spatial multiplexing is performed on BS-RS link
- Spatial multiplexing on RS-RS links is possible, but does not affect maximum sector throughput
- Maximum sector throughput is 150 units per frame
- Adding a third branch to the topology increases maximum sector throughput to 200 units per frame and so on

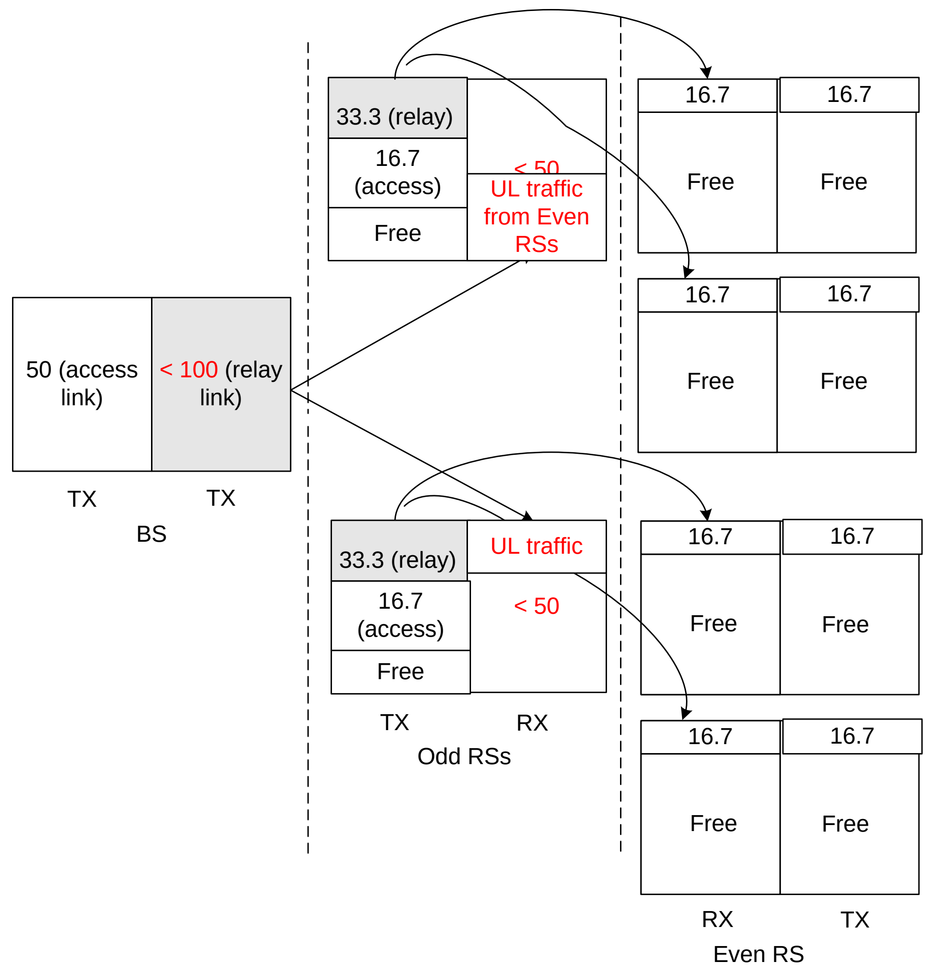


Spatial Multiplexing on BS-RS link is Critical

- Increasing spectral efficiency of BS-RS link (in relay zone of BS frame) is the most important way to increase maximum sector throughput in a system with RSs
- Different approaches for increasing spectral efficiency of relay zone may be used
  - Higher order modulations
  - Spatial multiplexing
- Spatial Multiplexing is a critical technique for increasing spectral efficiency for this link

Sector Throughput in FS Option 2 DL with Spatial Multiplexing

- Relay zone in Option 2 BS frame structure supports BS-RS DL and RS-RS UL
- BS cannot easily transmit to RSs during the part of the zone in which they receive UL transmissions from their subordinates
  - This either results in a decrease in maximum sector throughput
  - Or RS must implement complex SM techniques allowing BS and subordinate RS to transmit different data streams simultaneously; Variant B of symbol structure would need to be used, increasing pilot overhead

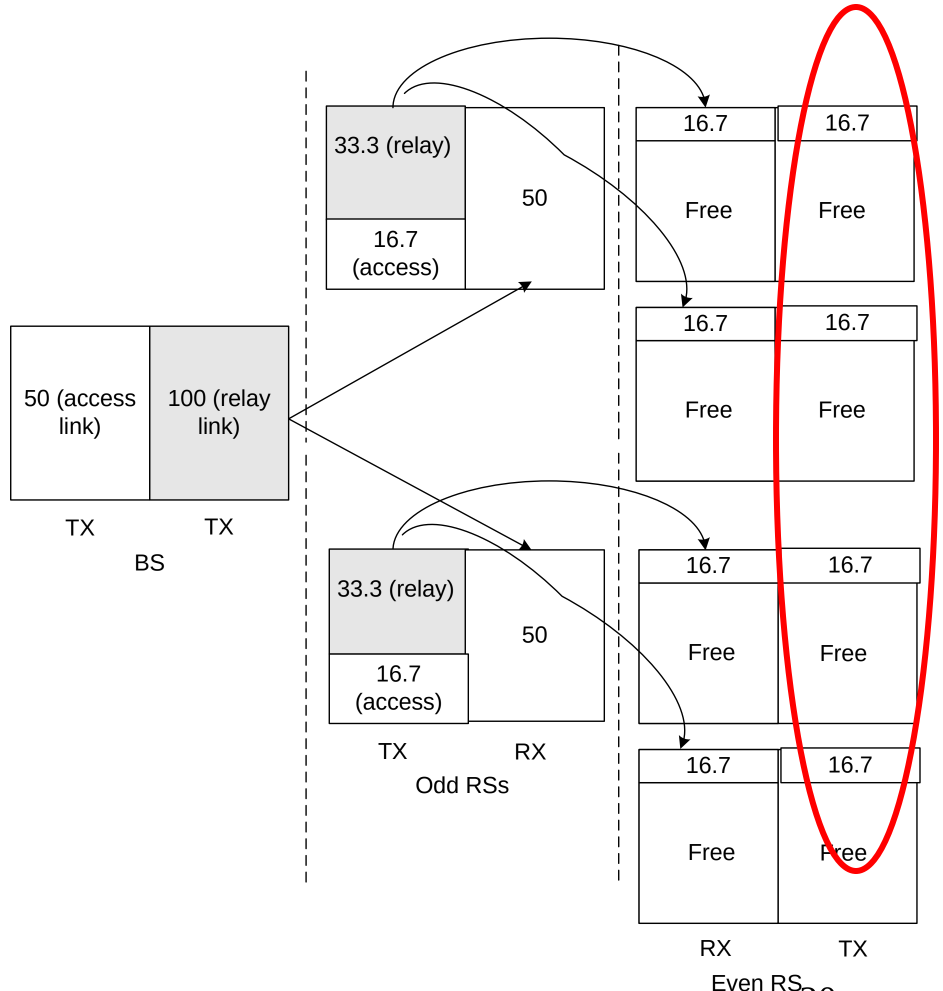


Sector Throughput Conclusions

- Efficiency of BS-RS link is the key to sector throughput in a relay system
- Spatial multiplexing is essential on the BS-RS link
- Option 1 FS supports maximum opportunities for spatial multiplexing on BS-RS link
- Option 2 FS complicates spatial multiplexing on BS-RS link because RS-RS link UL transmissions are supported in the same zone as BS-RS DL transmissions
  - Opportunities for spatial multiplexing are limited
  - Or complex scheme to allow simultaneous transmissions from BS and subordinate RSs must be implemented
- The same logic applies to the uplink

Switching Point Overhead

- FS Option 1 has 3 extra switching points in even tier RSs.
- Assume the same example as in slide 16.
- Because amount of traffic transmitted by the third tier RSs is smaller then the previous tier, these extra gaps should have no effect on capacity



DL/UL Ratios

- Option 1:
  – DL and UL are split for both access and relay zones, so various ratios can be supported
    - DL/UL Ratios without Legacy zones: 3:5, 4:4, 5:3, 6:2, 8:0
    - DL/UL Ratios with Legacy zones: 4:4, 5:3, 8:0
- Option 2:
  – Bidirectional zones are problematic because TX and RX (and thus DL and UL) flip from tier to tier.
  – Ratios other than 1:1 are problematic
  – See next slide for an illustration

DL/UL Ratios with Option 2

Zones must be split according to DL/UL ratio because all traffic flows through the BS, so the DL/UL ratio must exist in the BS frame

- In example on the right we assume DL/UL Ratio of 5:3
- 6:2 ratio is more problematic
- 2:6 and 3:5 ratios are also problematic, but these are not commonly used.

Odd hop RS receives 2 subframes of DL data from BS has only 1 subframe to transmit DL data to its subordinates

Loading Considerations

- Loading is defined as the amount of MS traffic being served by a BS or RS (to directly connected MSs)
- Relay topologies may come with different loading assumptions
  - Relative loading of BS vs RSs
  - Relative loading of RSs across tiers
  - Relative loading between RSs within each tier
- MS motion and bursty traffic will skew the nominal load
- Need to evaluate FS options relative to their ability to support the load of expected topologies and their ability to tolerate dynamic variations in this load.

Loading between tiers

- This applies only to >2 hop topologies
- Loading between tiers of RSs is constrained by the odd/even structure of both FS options.
- Both FS options have the same constraints

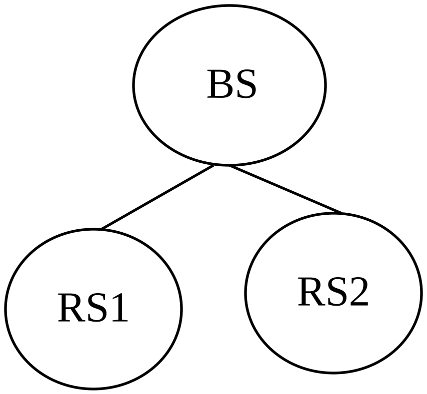
Loading between RSs within a tier

- Key consideration here is whether spatial reuse is assumed (on both relay and access links)
- If no spatial reuse, then it is no problem to adapt to unequal loading between the RSs
- If spatial reuse is assumed
  - Maximum SE is achieved when loading is uniform
  - As loading becomes less uniform, the possibilities for reuse decrease and SE decreases
  - This is true for both FS options

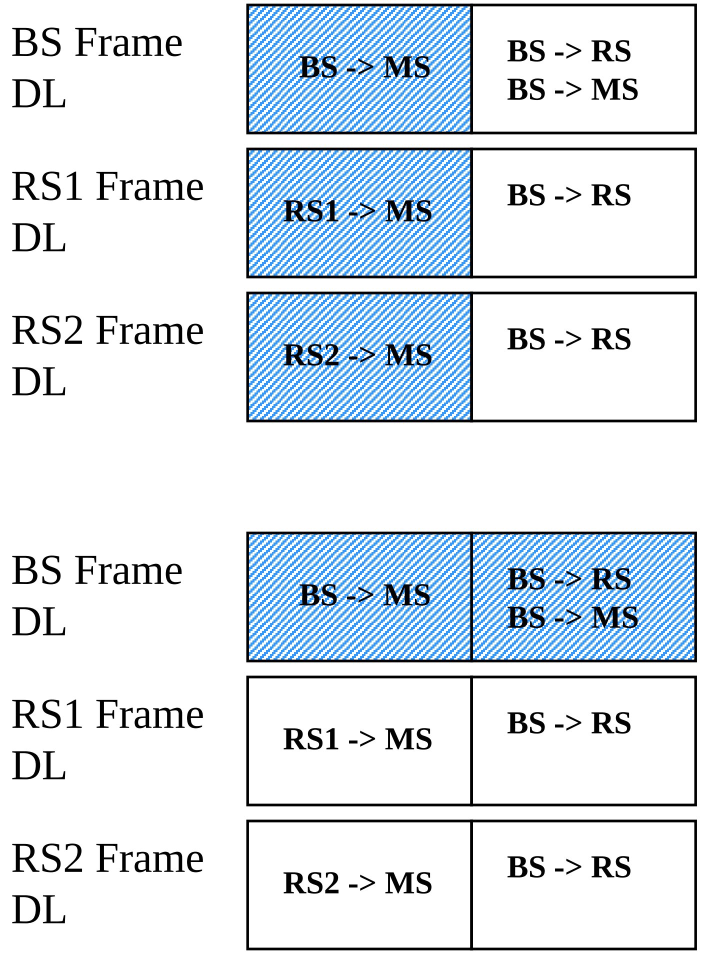
Loading between BS and RSs

- FS Option 1
  - BS can communicate with MS in both zones.
  - BS can dynamically accommodate changes in BS/RS loading from the provisioned ratio up to 100% traffic being served by the BS. See next slide for an example
- FS Option 2
  - FS does not adopt to changes in the split because BS cannot schedule transmissions to MSs in the relay zone

Example of Adapting to Changes in BS/RS Loading



- Assumptions:
  - Spectral efficiency of relay link 2x of access link SE
  - Even size zones
- In a topology with more RSs % of load handled by BS can be reduced to smaller numbers



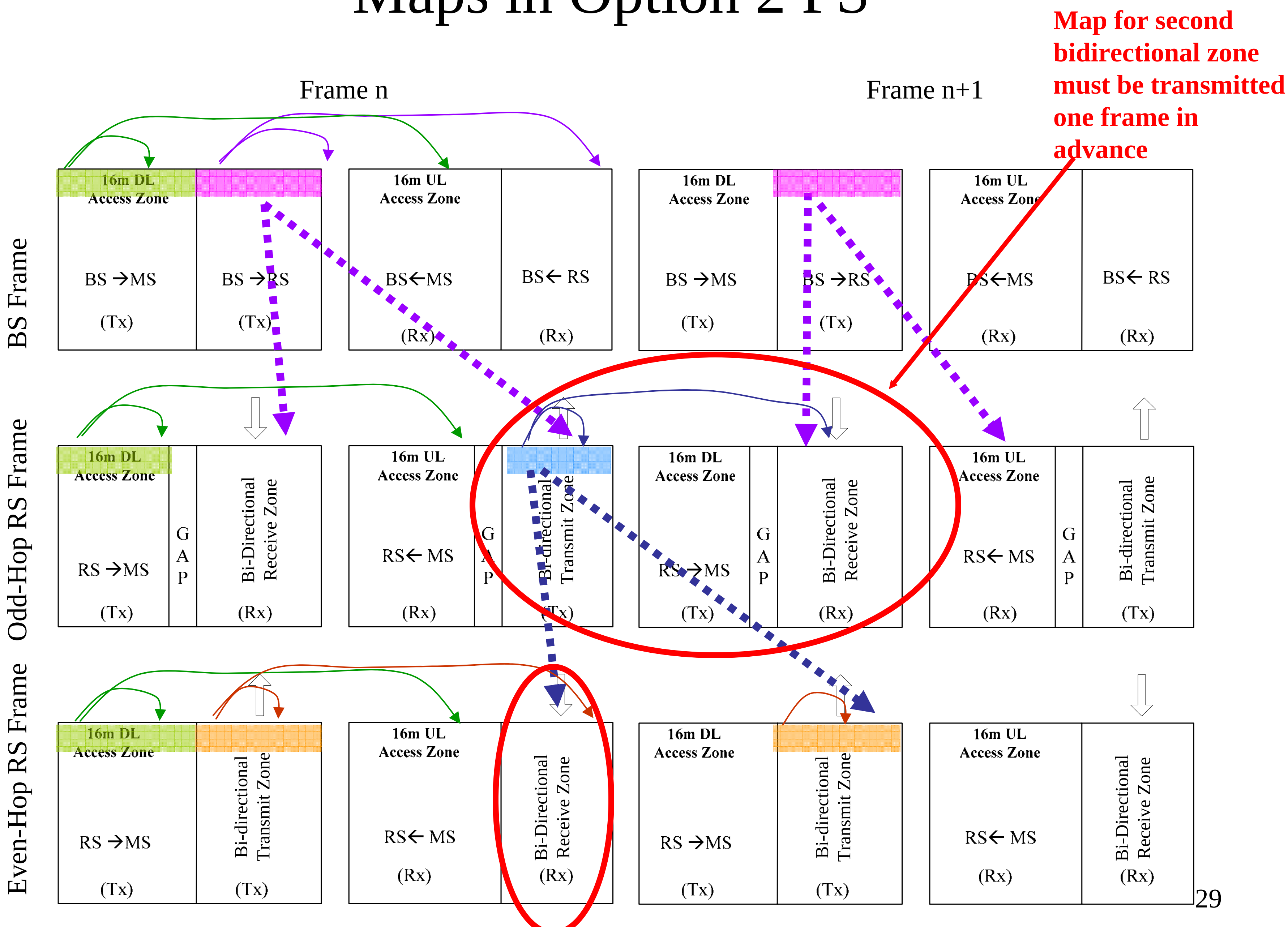
Nominal BS/RS loading ratio is 33% BS and 66% RSs

Maximal BS/RS loading ratio is 100% BS and 0% RSs

Map Support Considerations

- Map support for Option 1 is straightforward. One map, transmitted by one station describes all allocations in a zone
- Map support for Option 2 is more complicated.
  - Allocations within bidirectional relay zones are described by two maps, transmitted by two different stations.
  - Additional latency may be incurred because map must be transmitted one frame in advance

Maps in Option 2 FS



Relay zones allocations are described in two maps transmitted in different zones by different stations

Scheduling

- Option 1
  - Centralized and distributed scheduling works with no restrictions
- Option 2
  - Centralized scheduling works; changes in DL/UL regions in bidir zone can occur no more often than every superframe when using symbol structure variant A
  - Distributed scheduling
    - Allocations within bidirectional relay zones are scheduled by two different stations
    - In symbol structure variant A, the DL and UL are split in a semi-static manner and different stations schedule the DL and UL, coordination to determine this split is required. Coordination is not required to make allocations within the partition.
    - In symbol structure variant B the two stations must coordinate their scheduling efforts. The benefits of having a dynamic DL/UL split are diminished due to the latency of this coordination
- Conclusion is that scheduling and particularly distributed scheduling is simpler in Option 1

Latency Analysis

- Assume that RS needs 2 subframes to decode/encode data
- Option 1:
  - Two hop latency = 2f (where f = frame duration)
    - May be 1f for UL if UL is between 4 and 6 subframes in length
  - Three hop latency = 3f
    - May be 2f for DL is DL is between 4 and 6 subframes in length
- Option 2:
  - Two hop latency = 2f
    - May be 1f for UL if UL is between 4 and 6 subframes in length
  - Three hop latency
    - 2f in the UL
    - 2f or 3f in the DL depending on the DL/UL ratio.
      - 3f for 6:2 DL/UL ratio
      - For other ratios 2f latency cannot be guaranteed for all traffic because bidir zone in which odd hop RS receives data is immediately adjacent to the DL access zone in which it would have to transmit data to the MS. There may not be 2 subframes of separation in all cases, for all data.
- Two hop latency is the same for both options
- Option 2 has lower latency for 3 hops but not in all configurations and not guaranteed for all traffic

Multi-User MIMO

- FS option-1
  - Because access and relay link share the same zone, multi-user MIMO transmission can be done to MS-MS, RS-RS and MS-RS pairs
- FS option-2
  - Due to hard partitioning of access and relay zones, FS option-2 cannot support the MS-RS pairing for multi-user MIMO transmissions
  - If the number of RSs is small, there will be little multi-user diversity gain for RS-RS MU-MIMO.

Support for Cooperative Relay

- Option 1 FS
  - All forms of CR supported between the following:
    - BS and all RSs
    - RSs within a tier (e.g., tier 1 RSs)
    - RSs in odd tiers
    - RSs in even tiers
  - Only Asynchronous CR can be supported between RSs in different tiers.
- Option 2 FS
  - No restrictions on who can cooperate from a FS perspective
  - Interference in the DL may limit the gains from cooperation between adjacent tiers

Summary – Option 1 is the Better Choice

	2 hop topology	>2 hop topology
Sector Throughput	Same	Option 1 (higher maximum sector throughput)
DL/UL Ratio	Same	Option 1 (Option 2 does not support ratios other than 1:1 well)
Symbol Structure	Same	Option 1 (less complexity)
Loading	Option 1 (more flexibility to variation in BS/RS load)	Option 1 (more flexibility to variation in BS/RS load)
SCH	Same	Same
MBS	Same	Same
Maps	Same	Option 1 (less complexity)
Scheduling	Same	Option 1 (less complexity)
Latency	Same	Option 2 (2 frame duration latency in 3 hop topology in most cases)
Gap Overhead	Same	Same
Cooperative relay	Same	Same
MU-MIMO	Option 1 (more opportunities for SM)	Option 1 (more opportunities for SM)

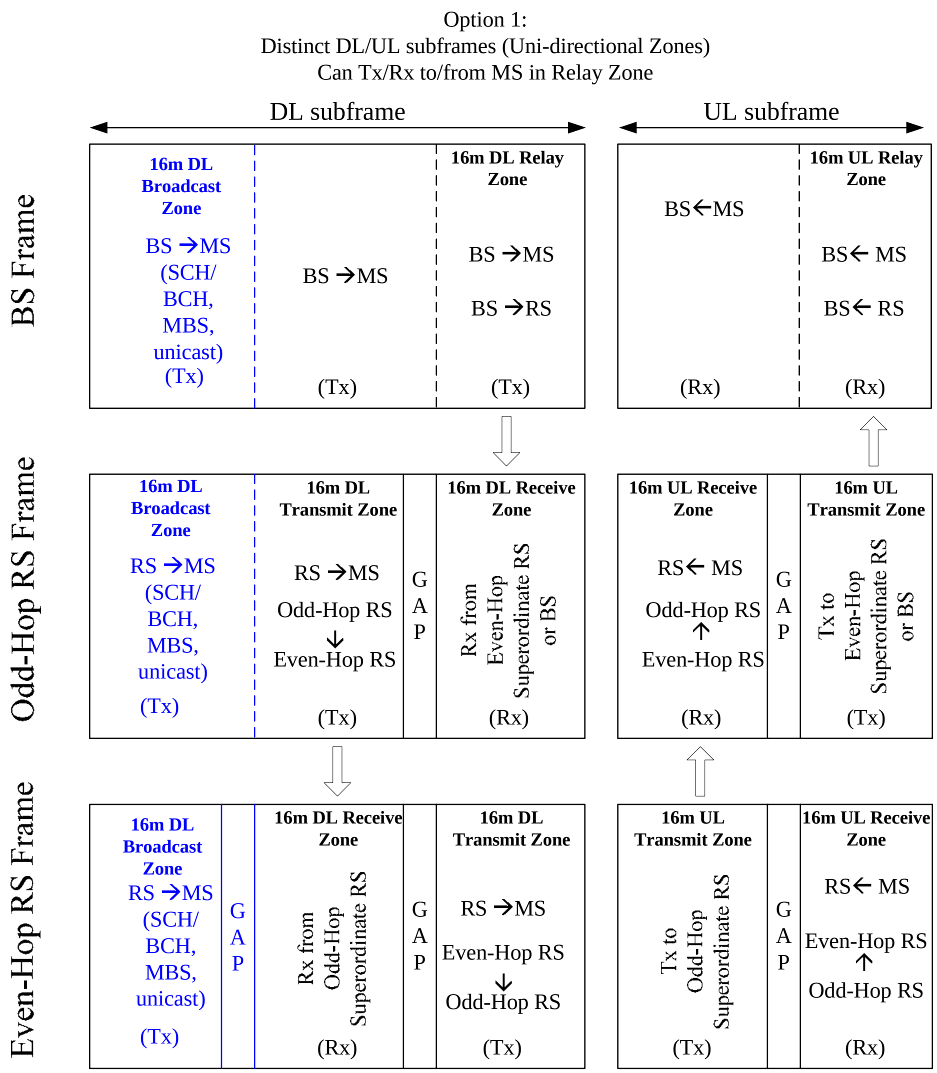
Proposed Text

Adding Broadcast zone to FS Option 1

[Modify figure 23 on page 40 as indicated in the figure on the right]

[Add the following text to the list of definitions that follow figure 23 on page 40 and 41]

- 16m DL Broadcast Zone: An integer multiple of subframes located in the 16m zone of the DL of the 16m BS frame or 16m RS frame, where a 16m BS or a 16m RS transmits the SCH and BCH. MBS transmissions and unicast transmissions to the MSs may also occur in this zone.



Proposed Text

Selection of FS Option 1 and removal of FS Option 2

[Modify the text in section 11.4.4 Relay Support in Frame Structure on page 39 as indicated below]

~~There are two options for the Relay frame structure. These are captured in Figure 23 and Figure 24. Further study is required to distill a single frame structure from among these two options~~. The Relay frame structure is illustrated in Figure 23.

[Delete the following text from the top of figure 23 on page 40]

~~Option 1: Distinct DL/UL Subframes (Unidirectional Zones) Can Tx/Rx to/from MS in Relay Zone~~

[Modify the caption of figure 23 on page 40 as indicated below]

Figure 23 Relay Frame structure ~~option 1~~

[Delete figure 24 from page 42]

[Delete the text that follows figure 24 on page 42 lines 3-11 and page 43 lines 1-2 up till the end of section 11.4.4]

Proposed Text

Improvements to Zone definitions for Option 1 (slide 1)

[Modify the text in section 11.4.4 on pages 40 and 41 as indicated below]

- DL Access Zone: An integer multiple of subframes located in the 16m zone of the DL of the 16m BS frame, where a 16m BS can transmit to the 16m MSs.
- ~~DL Relay Zone: An integer multiple of subframes located in the 16m zone of the DL of the BS frame, where a 16m BS can transmit to the 16m RSs and the 16m MSs~~.
- DL Access Zone: An integer multiple of subframes located in the 16m zone of the DL of the 16m BS frame, where a 16m BS can transmit to the 16m MSs.
- ~~UL Relay Zone: An integer multiple of subframes located in the 16m zone of the UL of the 16m BS frame, where a 16m BS can receive from the 16m RSs and the 16m MSs~~.
- DL Transmit Zone: An integer multiple of subframes located in the 16m zone of the DL of the 16m BS frame or 16m RS frame, where a 16m BS or RS can transmit to subordinate 16m RSs and the 16m MSs.
- DL Receive Zone: An integer multiple of subframes located in the 16m zone of the DL of the 16m RS frame, where a 16m RS can receive from its superordinate station.
- UL Transmit Zone: An integer multiple of subframes located in the 16m zone of the UL of the 16m RS frame, where a 16m RS can transmit to its superordinate station.
- UL Receive Zone: An integer multiple of subframes located in the 16m zone of the UL of the 16m BS frame or 16m RS frame, where a 16m BS or RS can receive from its subordinate 16m RSs and the 16m MSs.

Proposed Text

Improvements to Zone definitions for Option 1 (slide 2)