Relay with network coding support

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Venue:
IEEE 802.16m-08/040“Call for Contributions on Project 802.16m System Description Document (SDD)”, in response to the following topics: “Support for relay”, MAC related

Base Contribution:

N/A

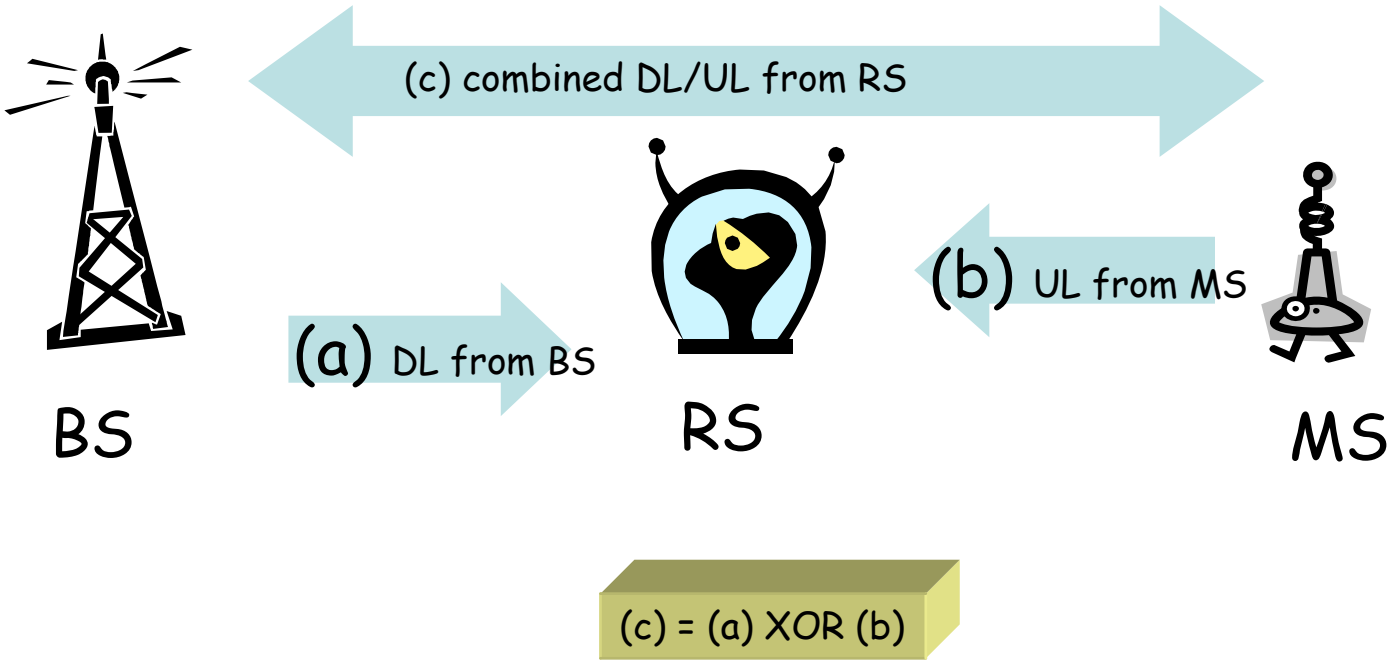
Purpose:

For TGm discussion and adoption of 802.16m SDD text.

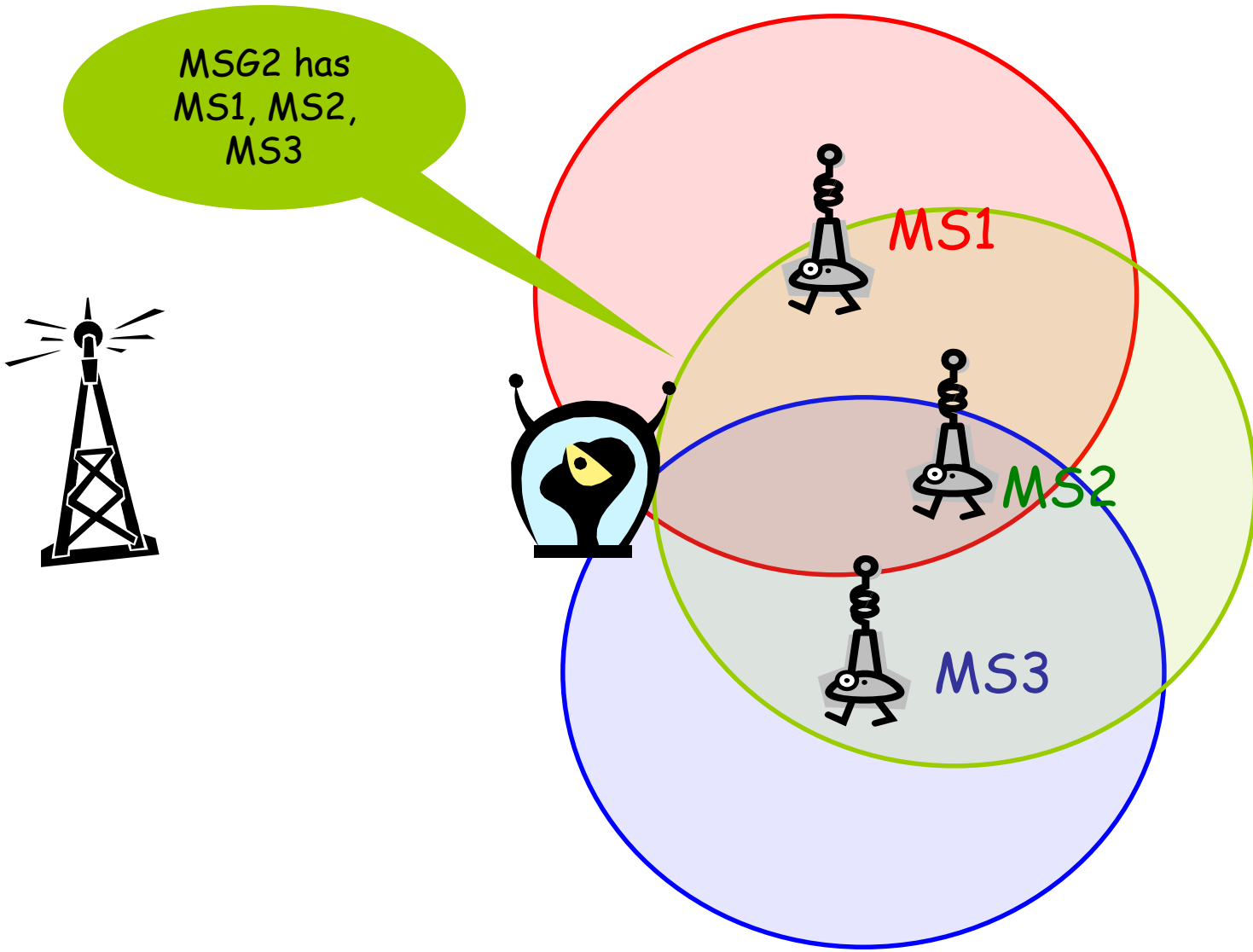
Proposed RS types

- ARQ: end to end
- Security: end to end
- HARQ:
  - Hop by hop
  - Between the super-ordinate node of access RS, access RS and MS (for cross-tier co-operative relay)
- DL
  - distributed scheduling
    - Transmission from the access RS may be made compatible to the transmission from the super-ordinate node of access RS, if MS reports strong CQI from this node
- UL
  - Un-scheduled UL from access RS
    - DL access resource are also used for UL relay/signaling, or
    - a portion of UL resources reserved/scheduled for an access RS. The access RS determines the MCS, resource allocation of each burst within this portion.
  - Non-transparent, centralized scheduling from the super-ordinate node of access RS
    - Scheduling of relay link may be optional if access RS uses Un-scheduled UL
    - Transmission from the access RS may be made compatible to the transmission from the MS, if MS reports strong CQI from the super-ordinate node of access RS
  - Distributed scheduling
    - Scheduling of relay link may be optional if access RS uses Un-scheduled UL
    - Transmission from the access RS may be made compatible to the transmission from the MS, if MS reports strong CQI from the super-ordinate node of access RS

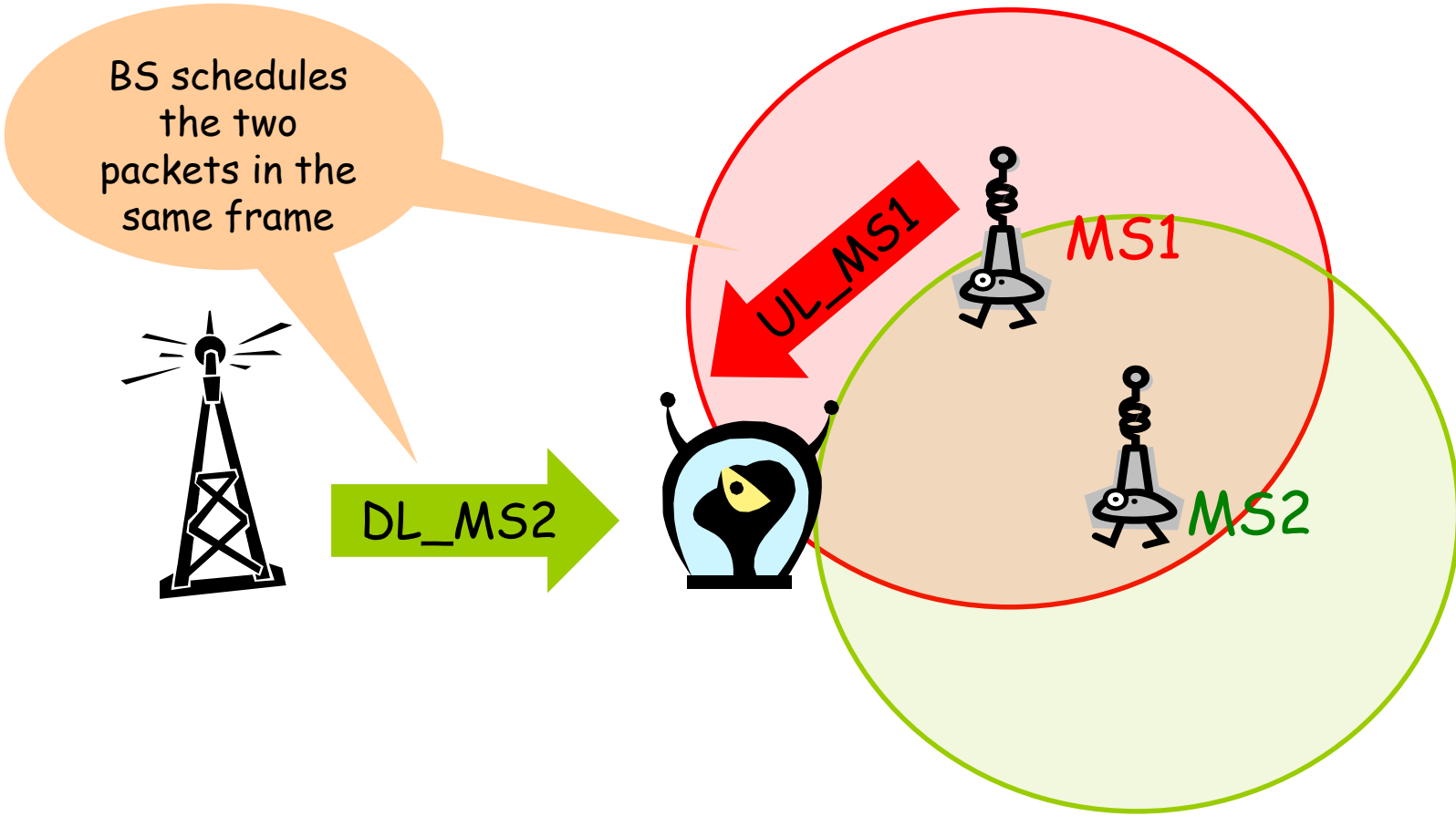
RS in a cellular network using network coding (NC)



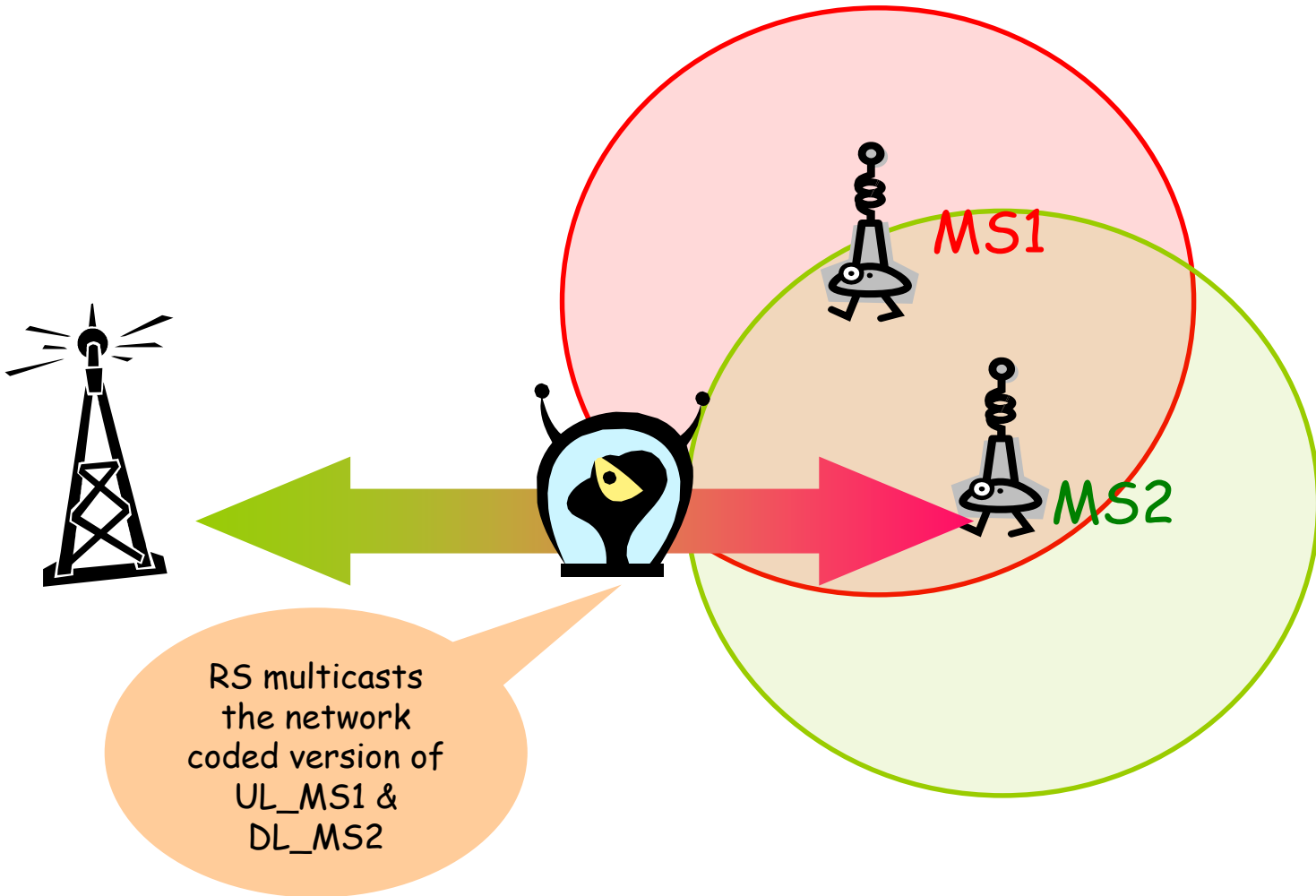
MS Group (MSG)



BS schedules based on MSG



RS sub-frame


MS1
MS2
RS multicasts the network coded version of UL_MS1 & DL_MS2

MSG & BS Scheduling

- Each MS maintains a MS Group (MSG) consisting of the neighboring MSs whose MSG report is decodable during UL sub-frame
- MS reports its MSG to BS periodically
- BS scheduler pairs the transmissions of a DL packet to MS2 and an UL packet from MS1, with MS1 in MS2's MSG, to maximize the possibility that network-coded transmission can be used if there is a retransmissions by RS
- MS1 & MS2 can be the same MS

FS dependencies

- NC may be operated with both choices of FS options
  - FS option 1: DL RS Tx zone, hop count ≥3
  - FS option 2: Bi-directional Tx zone

Numerical results

- For the comparisons of amount of BW usages with/without NC
- Assumptions:
  - Each UL/DL packet uses the same amount of resource
  - 1 HARQ retransmission (from either source or RS)
  - Pr=0.99, probability of RS decodes a DL/UL packet in the 1st HARQ transmission
  - Pm=0.1, probability of BS/MS decodes a UL/DL packet in the 1st HARQ transmission
  - 2-bit Ack from a DL MS
    - 00: ack for its DL packet d0
    - 01: ack for an UL packet u1 and nak for d0
      - u1 paired/grouped with d0
    - 10: ack for an UL packet u2 and nak for d0
      - u2 grouped with d0
    - 11: none of the ack above

Effects from MSG reliability, DL/UL=1

MSG reliability	Saved BW/ RS BW	Saved BW/ Total BW
0.9	40.10%	18.80%
0.8	35.64%	16.71%
0.7	31.19%	14.62%
0.6	26.73%	12.53%
0.5	22.28%	10.45%

- MSG reliability: probability of MS2 decoding UL packets from MS1, given MS1 in the MSG of MS2
- BS pairs a DL MS2 with an UL MS1

Effects from BS scheduling decision, DL/UL=3

x DL MSs grouped with an UL MS based on MSG reports	y remaining DL MSs	MSG reliability	Saved BW/ RS BW	Saved BW/Total BW
1	2	0.6	13.37%	6.27%
2	1	0.6	19.59%	9.18%
3	0	0.6	22.48%	10.54%
1	2	0.9	20.05%	9.40%

- When DL/UL ratio is high, BS may group multiple DL MSs with less number of UL MSs to improve MSG reliability
- Grouping applied to the case with low MSG reliability can perform better than the case with high MSG reliability and pairing

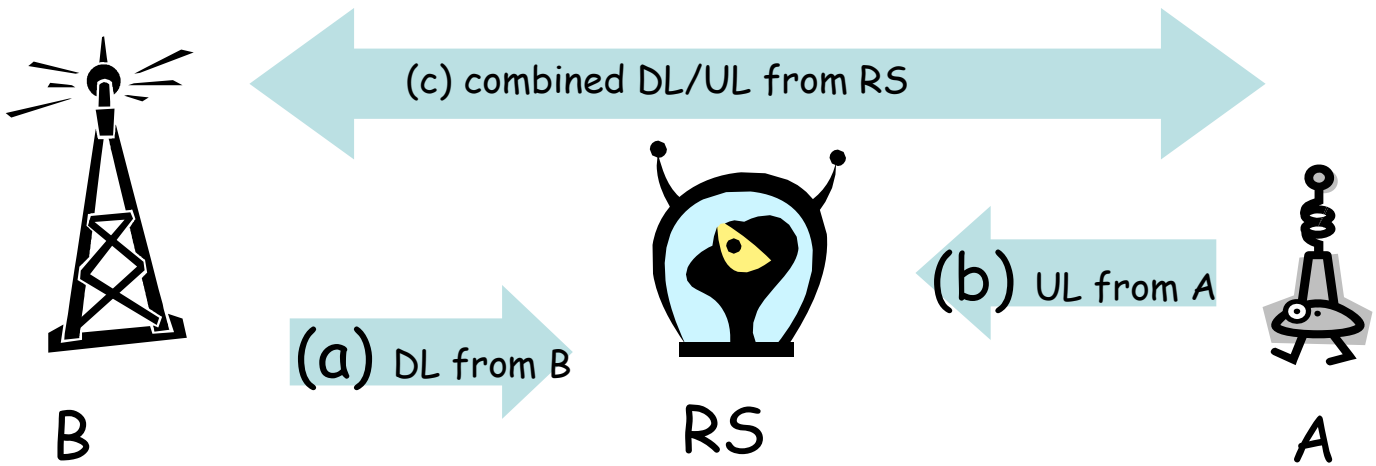
- BS schedules x+y=3 DL packets, and one UL packet (from MS0)
- MS0 is in the MSGs of x DL MSs
- MS0 is not in the MSG of y DL MSs

NC with link adaptation

- If NC is used by a RS to compress relay and access link traffic, the order of NC and channel coding affects link adaptation performance.
- Recommend to apply NC after channel coding
  - encoder code rate can be chosen to adapt individual receiver's channel condition. Procedures 3 and 4 in the next few slides are examples of this technique.

Comparison of #of symbols used in different NC procedures

- packet size from A to B, i.e. size of A_B: x
- packet size from B to A, i.e. size of B_A: kx
- A-RS channel condition gives spectral efficiency Sa
- B-RS channel condition gives spectral efficiency Sb
- “k >= 1” (without loss of generality)
- Following 4 procedures have different results on BW usage (# of modulation symbols)



Procedure 1: Padding → NC → channel coding

- The smaller packet is padded to kx bits
- NC packet is channel coded and transmitted with spectral efficiency min(Sa,Sb)
- Total # of modulation symbols used:
  - kx/min(Sa, Sb)

Procedure 2: Fragmentation → NC → channel coding

- NC x bits to both A & B, and unicast (k-1)x bits to A
- NC packet is channel coded and transmitted with spectral efficiency min(Sa,Sb)
- Total # of modulation symbols used:
  - x/min(Sa, Sb) + (k-1)x/Sa

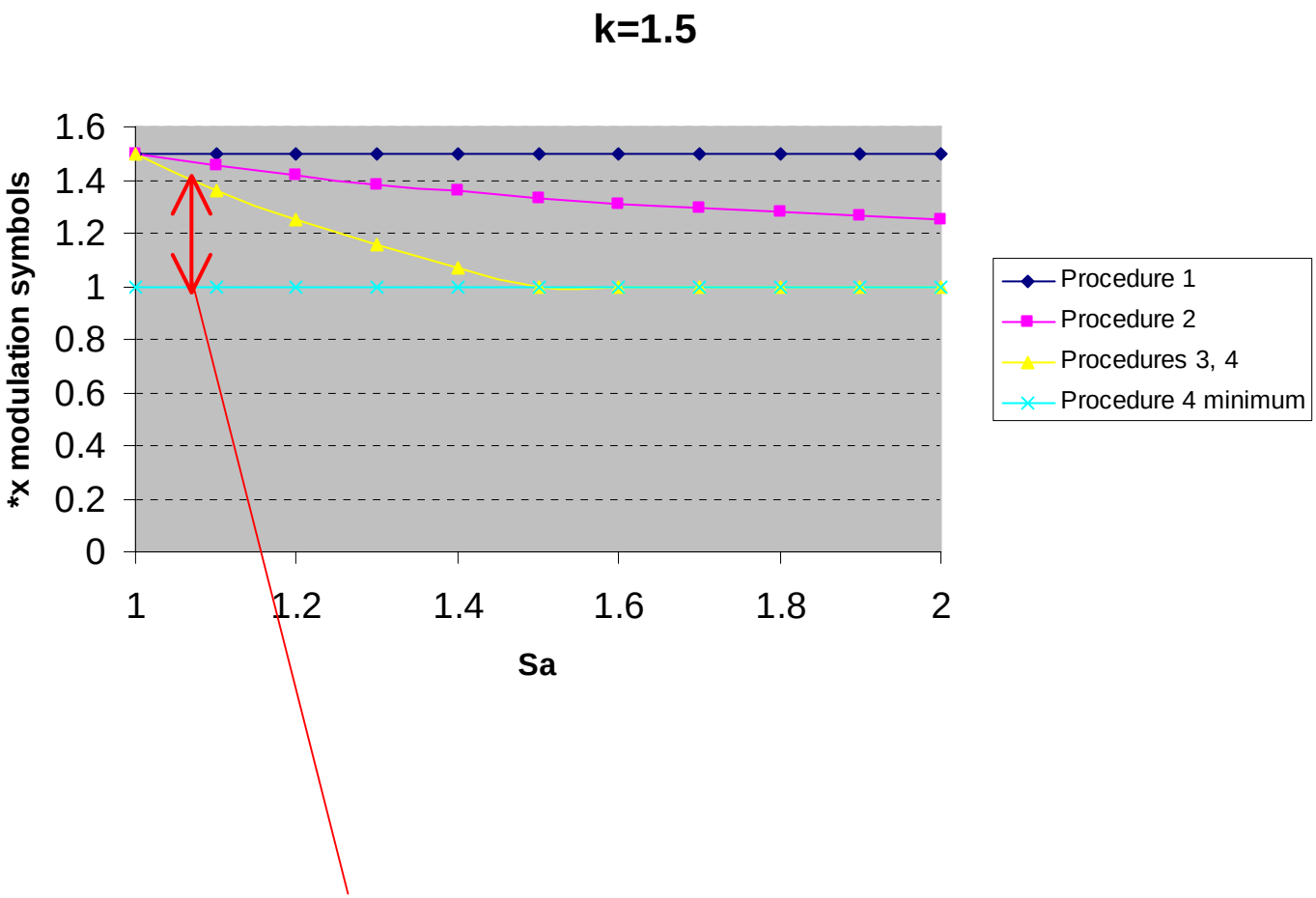
Procedure 3: Channel coding → NC

- # of required modulation symbols of packet to A after channel coding for Sa: kx/Sa
- # of required modulation symbols of packet to B after channel coding for Sb: x/Sb
- Transmit the packet with L'=max(kx/Sa, x/Sb)
  - L=min(kx/Sa, x/Sb)
  - Optionally before NC, additional parity modulation symbols can be added to have length L'
    - NC of L'-L symbols is optional
  - E.g. kx/Sa >= x/Sb
    - NC packet is transmitted to A with spectral efficiency kx/L'
    - NC packet is transmitted to B with spectral efficiency x/L' or x/L
- Total # of modulation symbols used:
  - L'=max(kx/Sa, x/Sb)

Procedure 4: Channel coding → NC → fragmentation

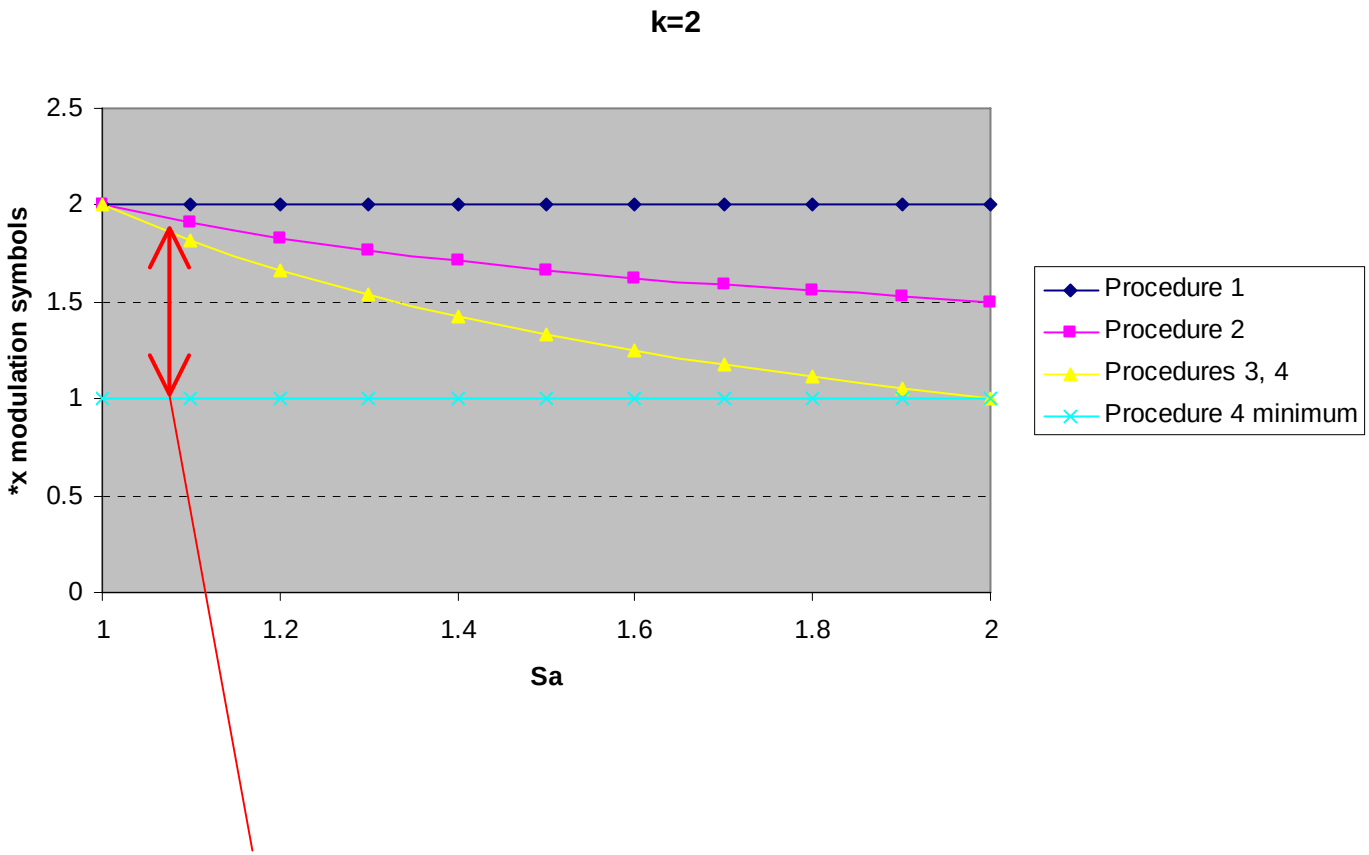
- # of required modulation symbols of packet to A after channel coding for Sa: kx/Sa
- # of required modulation symbols of packet to B after channel coding for Sb: x/Sb
- Transmit the NC packet with L=min(kx/Sa, x/Sb)
- NC L modulation symbols for MSA and MSB, and the rest of L'-L modulation symbols can either be unicasted or NC'ed with other packets' modulation symbols (e.g. L'-L symbols to A is NC'ed with a relayed packet (RS->B) originated from C. The packet has already been decoded by A during C->RS transmission)
  - E.g. kx/Sa >= x/Sb
    - NC packet is transmitted to MSA with spectral efficiency kx/L'
    - NC packet is transmitted to MSB with spectral efficiency x/L
- Total # of modulation symbols used (worst case):
  - L'=max(kx/Sa, x/Sb)
  - # of modulation symbols used may be reduced, for example:
    - The L'-L parity symbols to MSA can be NC'ed with with the encoded bits of a packet from C, which is in A's MSG
    - The L'-L parity symbols to A can be NC'ed with the encoded bits of a subsequent packet from A received by RS

Comparison (Sb=1)



Possible reduction of L'-L symbols by additional NC with a 3rd packet

Comparison (Sb=1)



Possible reduction of L'-L symbols by additional NC with a 3rd packet

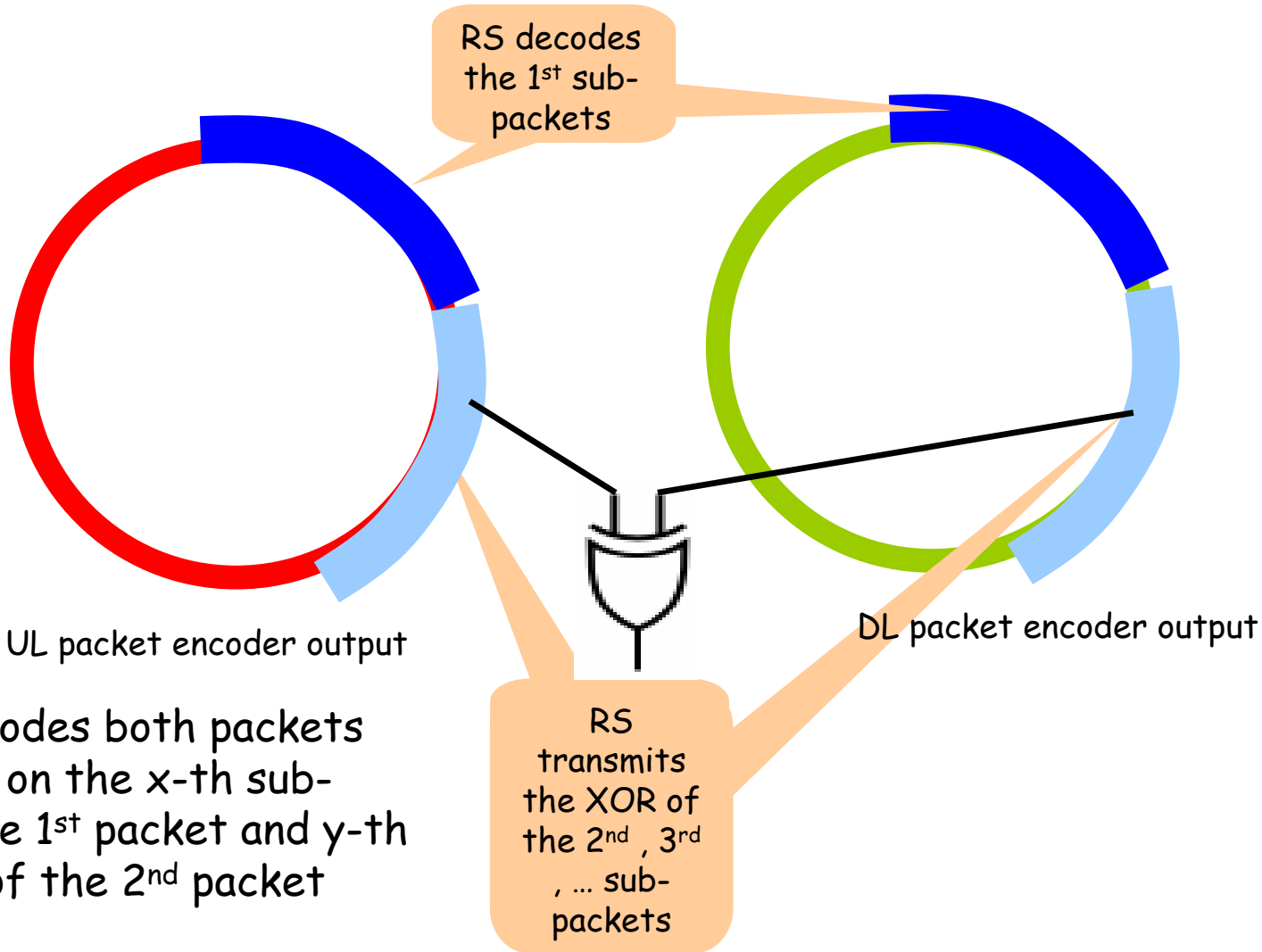
NC after channel coding - additional benefit

- Previous slides show the reduction of radio resources by RS encoding packets separately to adapt the channel and packet size on each link, before applying NC
- If RS serves as a cross-tier co-operative RS, the relayed burst must have a compatible channel coding with the burst from the source, so the destination can combine the two bursts
  - If RS NCs the information bits and then apply a channel coding, the destination cannot use the information/energy collected from the source transmission.

Co-operative relay support

- To support co-operative relay, the RS does not transmit a separated coded PHY packet
  - Instead, RS re-encodes the UL and DL packets and sends the XOR of the parity bits
  - BS/MS uses its own parity bits (not transmitted) to descramble the received parity bits, and decode the packets
- Receiver combines the information from both the source and RS (after de-scrambling) to decode the packet
- Co-operative relay with reduced RS BW consumption

Co-operative relay support



- Relay re-encodes both packets
- XOR is done on the x-th sub-packet of the 1st packet and y-th sub-packet of the 2nd packet

Proposed text

- MS should maintain a MS Group (MSG) consisting of the neighboring MSs whose MSG report is decodable
- MSG report, if available, shall be delivered to the super-ordinate node of access RS periodically. The MSG reports from different MS should be staggered
- RS may apply network coding to compress transmissions to its super-ordinate and sub-ordinate stations
- Network coding, if utilized by an RS, should be applied after channel coding to adapt to different packet sizes and link conditions at the receivers, as well as to facilitate cross-tier co-operative relay
- Channel coding of a DL transmission from an access RS may be made compatible to a transmission from the super-ordinate node of the access RS, if MS reports strong CQI from this node.
- Channel coding of an UL transmission from an access RS may be made compatible to the transmission from the MS, if MS reports strong CQI from the super-ordinate node of the access RS.