Video-aware Multicast Opportunistic Routing over 802.11 two-hop mesh networks

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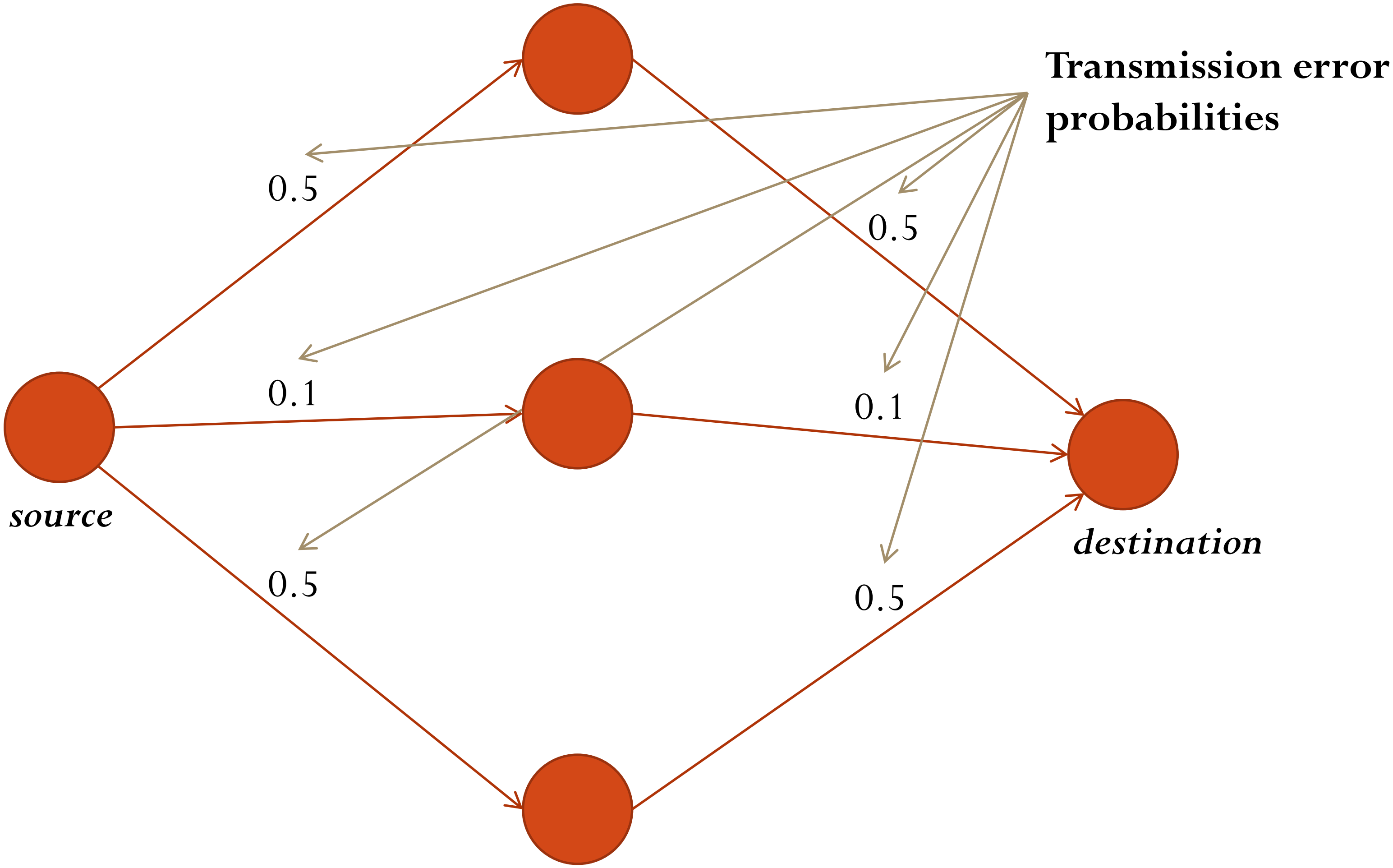
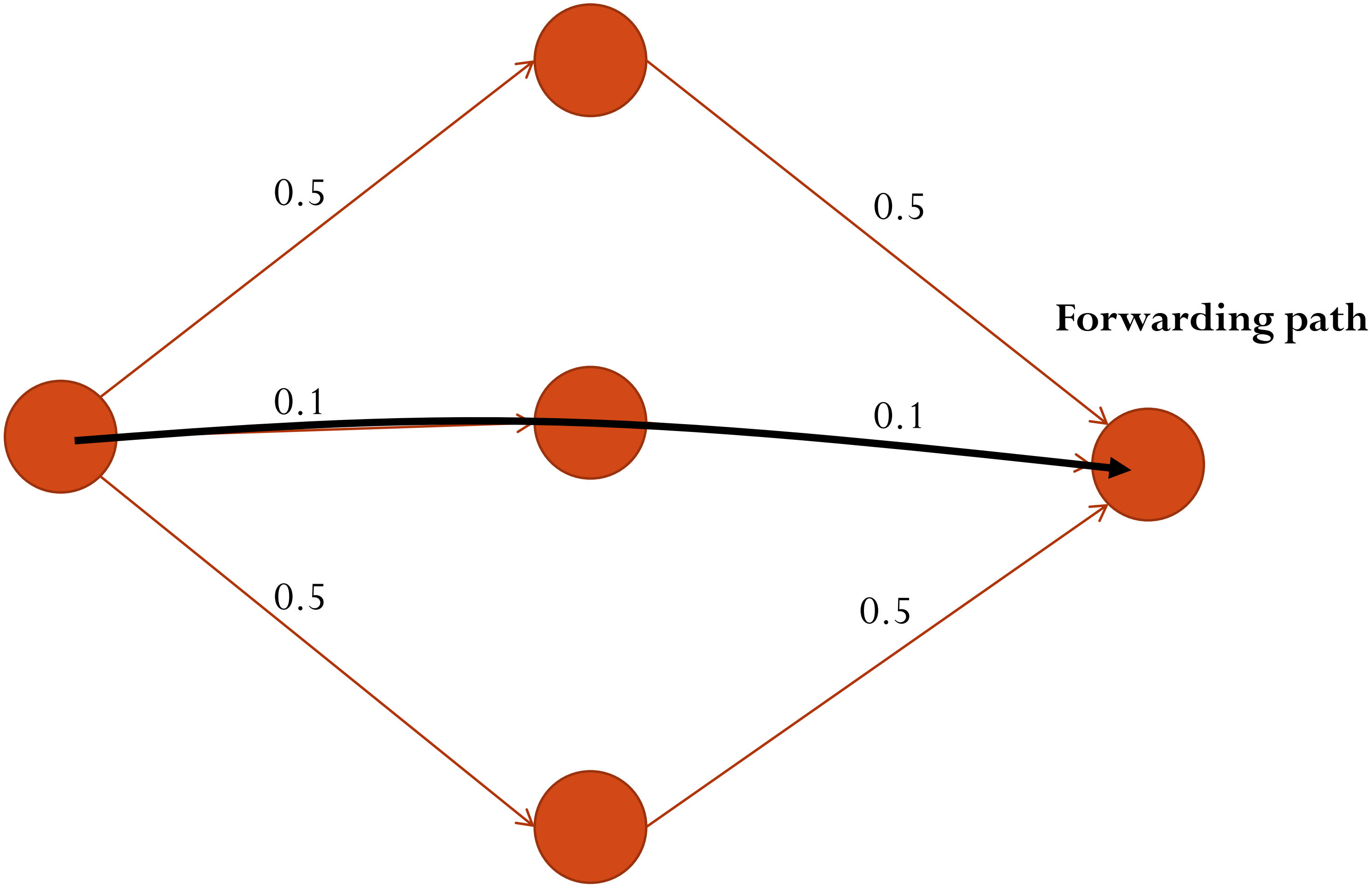
What is routing?



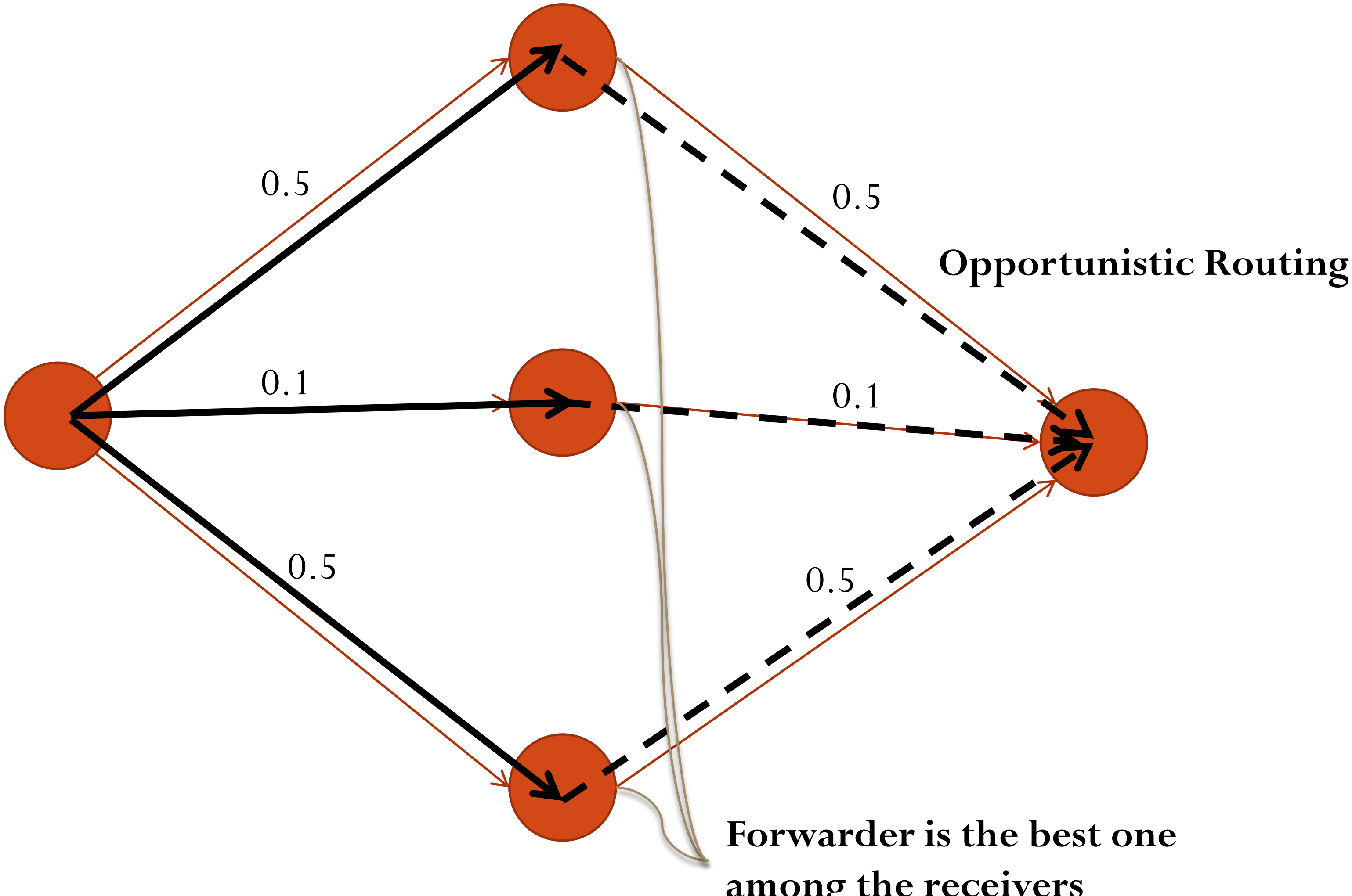
Shortest-path Routing



Opportunistic Routing (OR)

- OR could either:
  - *“Relay the received signal acting as multi-antenna system”*
  - *“Combine the bits received at different nodes to correct errors”*
  - ***“Optimize the choice of the next forwarder from the nodes that received a transmission”***
- We focus on the third approach!

Opportunistic Routing



Why Opportunistic Routing?

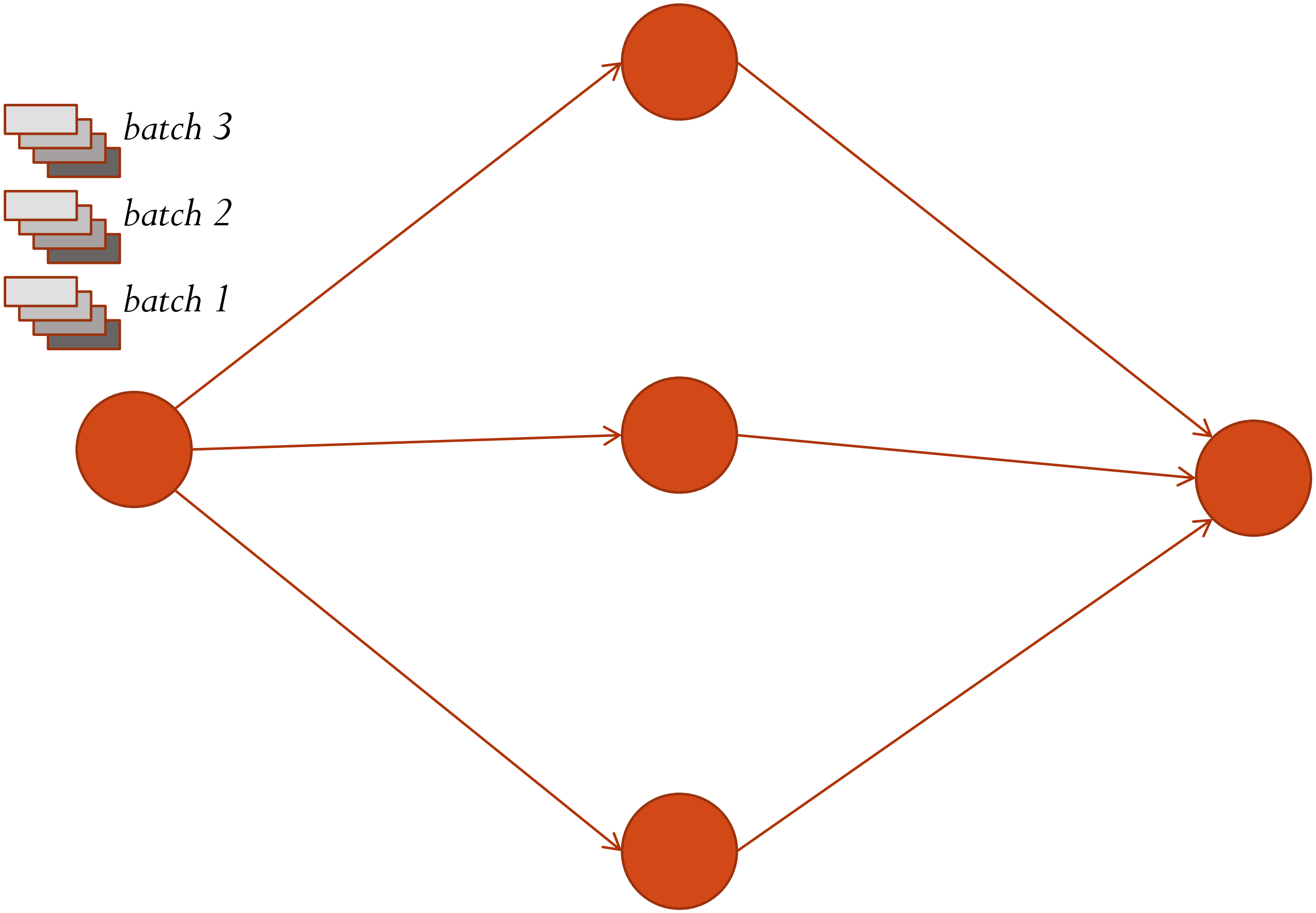
- Wireless access has increased popularity and efficiency
- Routing based on a shortest path comes from wired networks
  - Wired connectivity: reliable unicast transmissions
- Opportunistic Routing
  - Takes advantage of the wireless broadcast nature
  - Robust to the wireless transmission errors

ExOR (ACM SIGCOMM 2005)

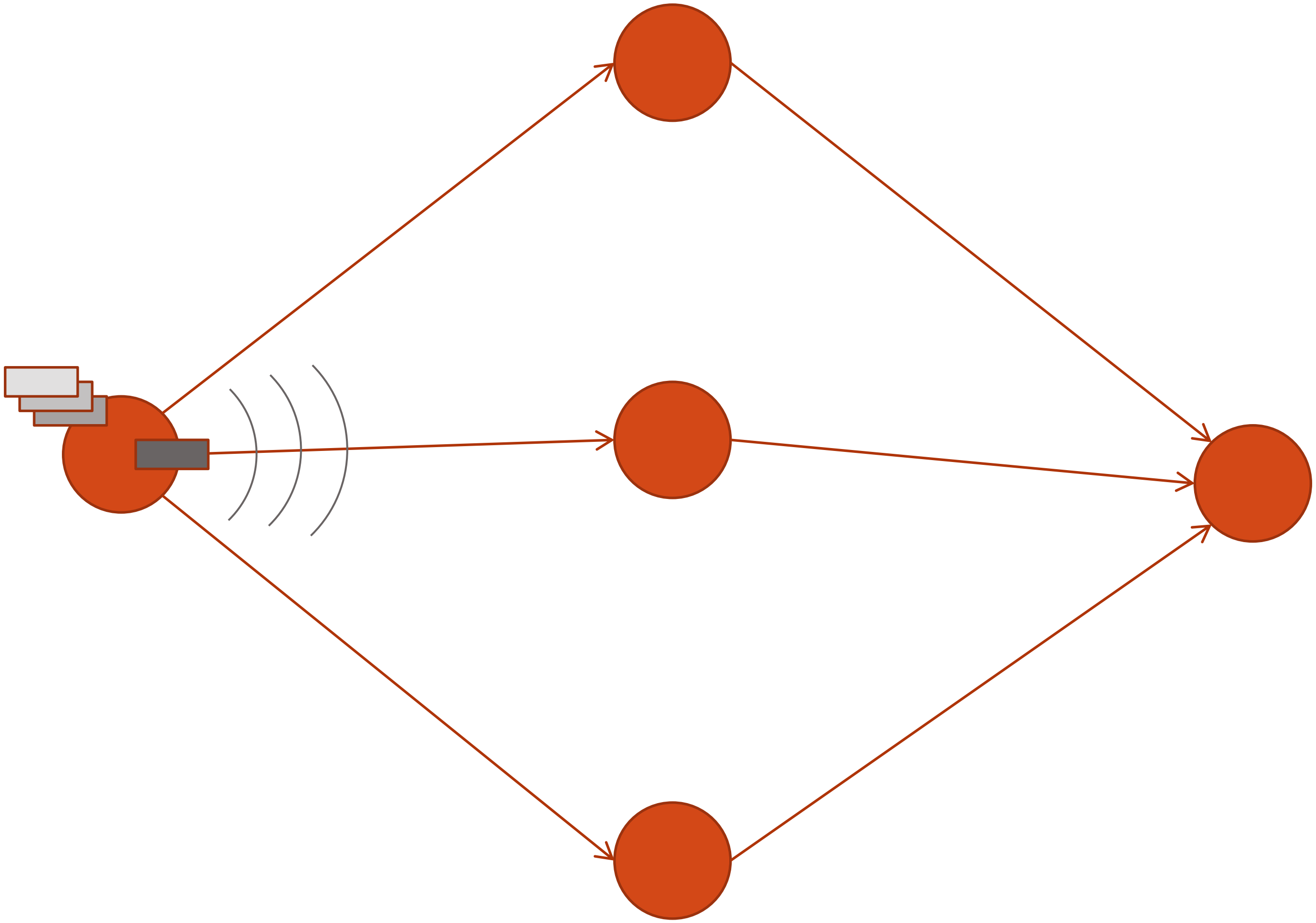
- First implementation
- Focus on unicast routing
- Avoids contentions/collisions, based on a modified MAC layer
- Process:
  1. Source separates the packets in *batches,* in order to send them collectively
  2. Source broadcasts the batch packets (limited times)
  3. Each potential receiver retransmits each of them (limited times)
  4. Destination sends an aggregate ACK using the shortest path, when it receives all batch packets
  5. Source proceeds to the following batch

  (Source uses shortest path if all transmitters exhaust their transmissions)

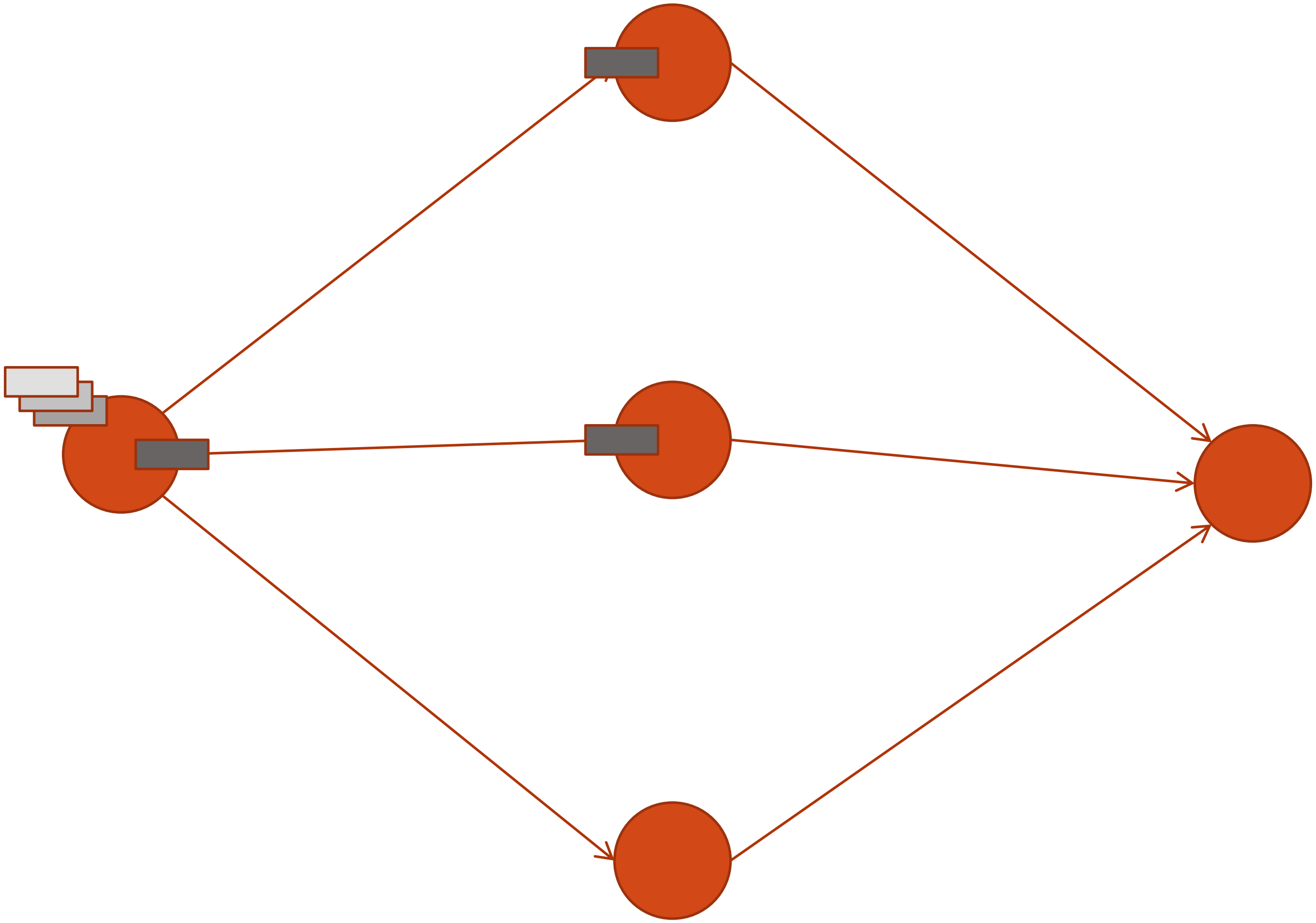
ExOR – Batches separation



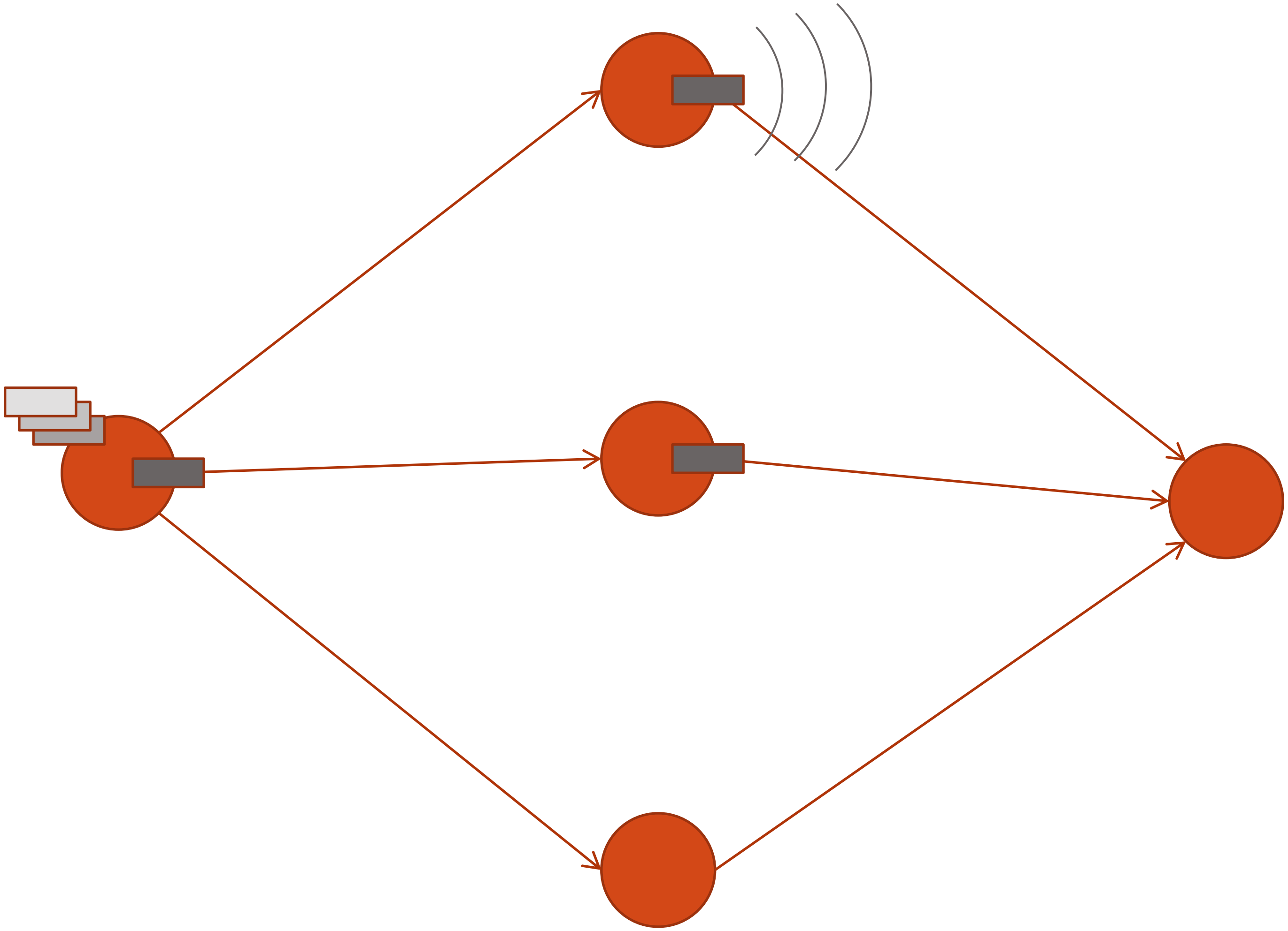
ExOR – Source broadcasts



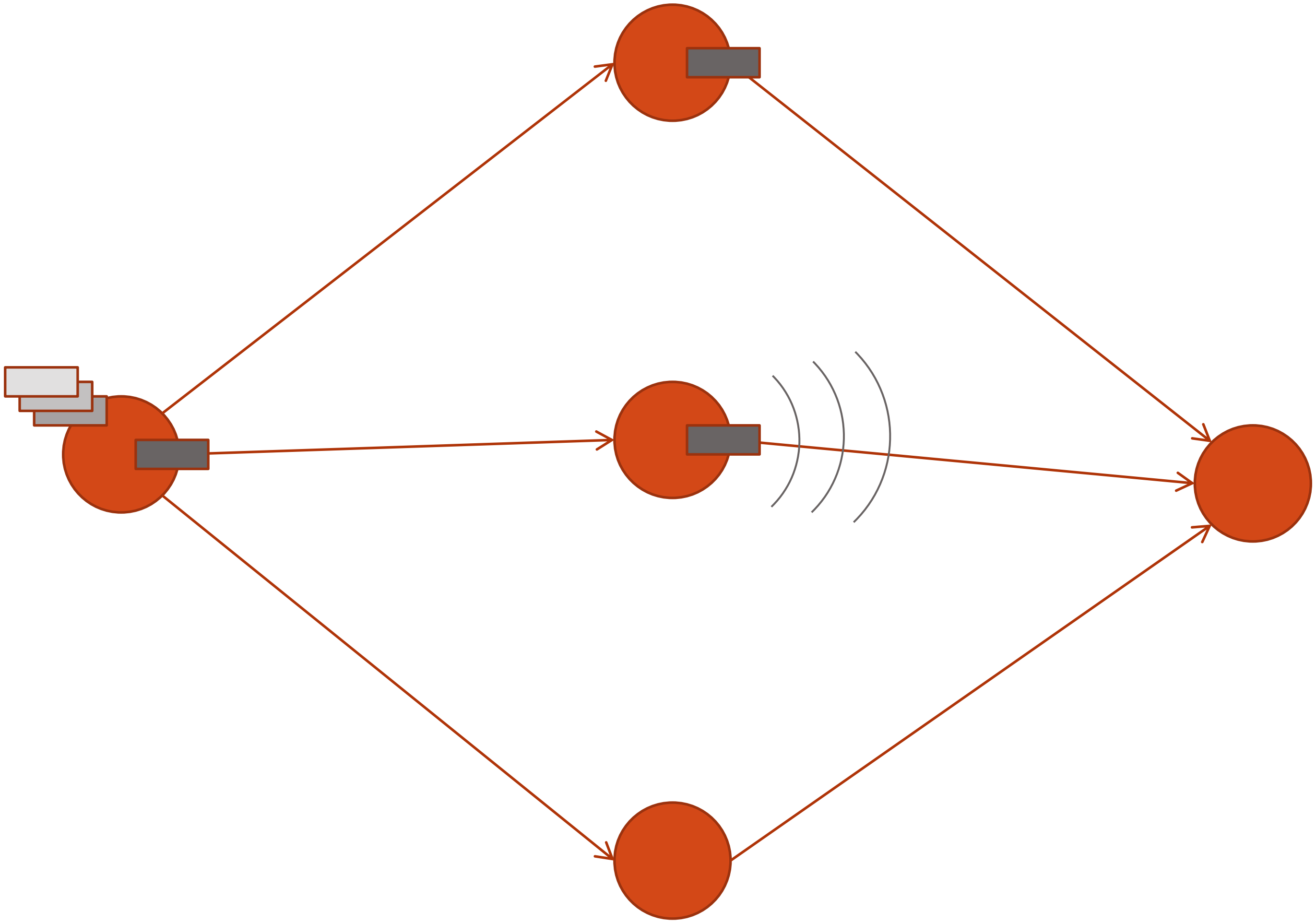
ExOR – Potential receivers



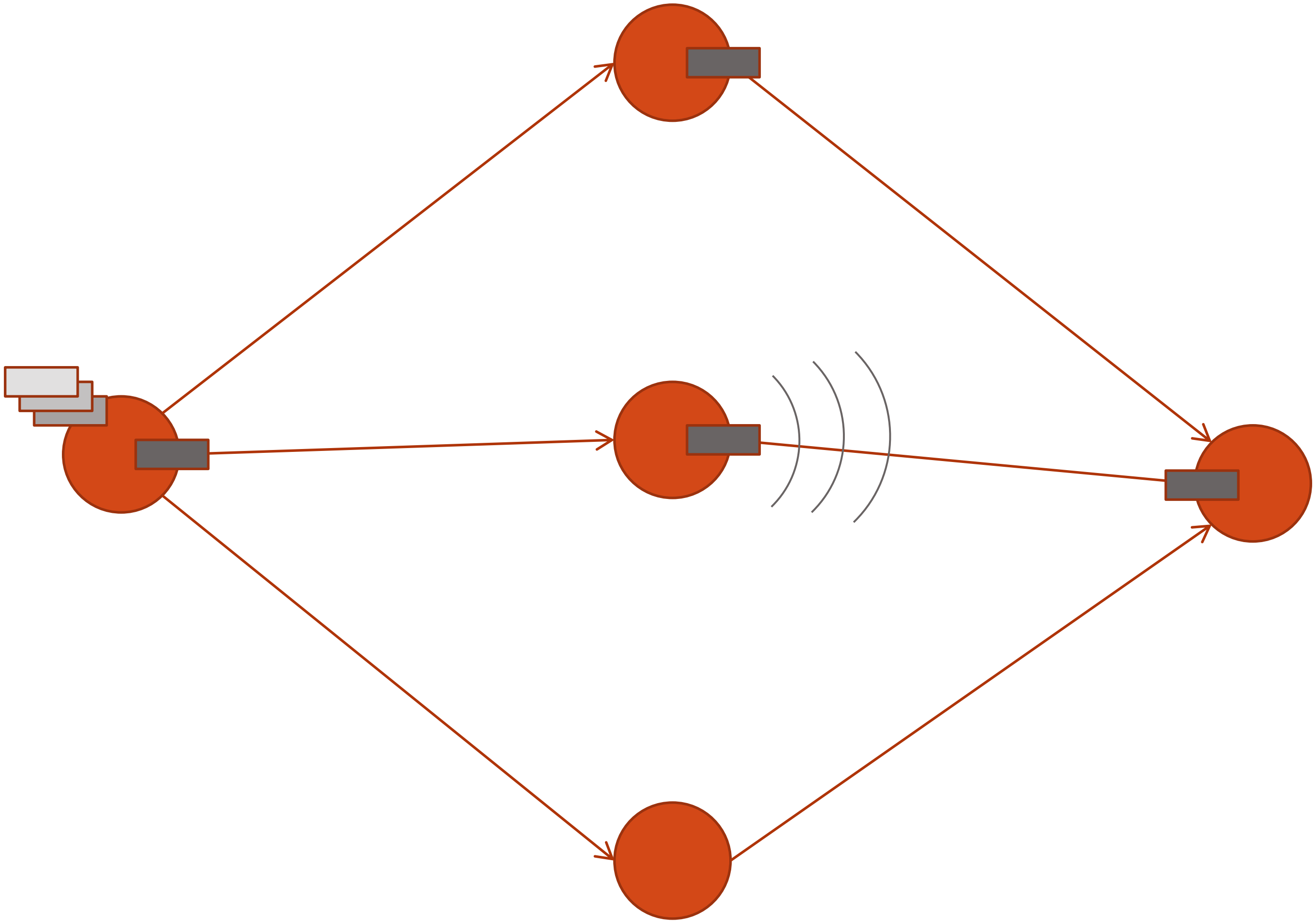
ExOR – Avoid collisions



ExOR – Avoid collisions

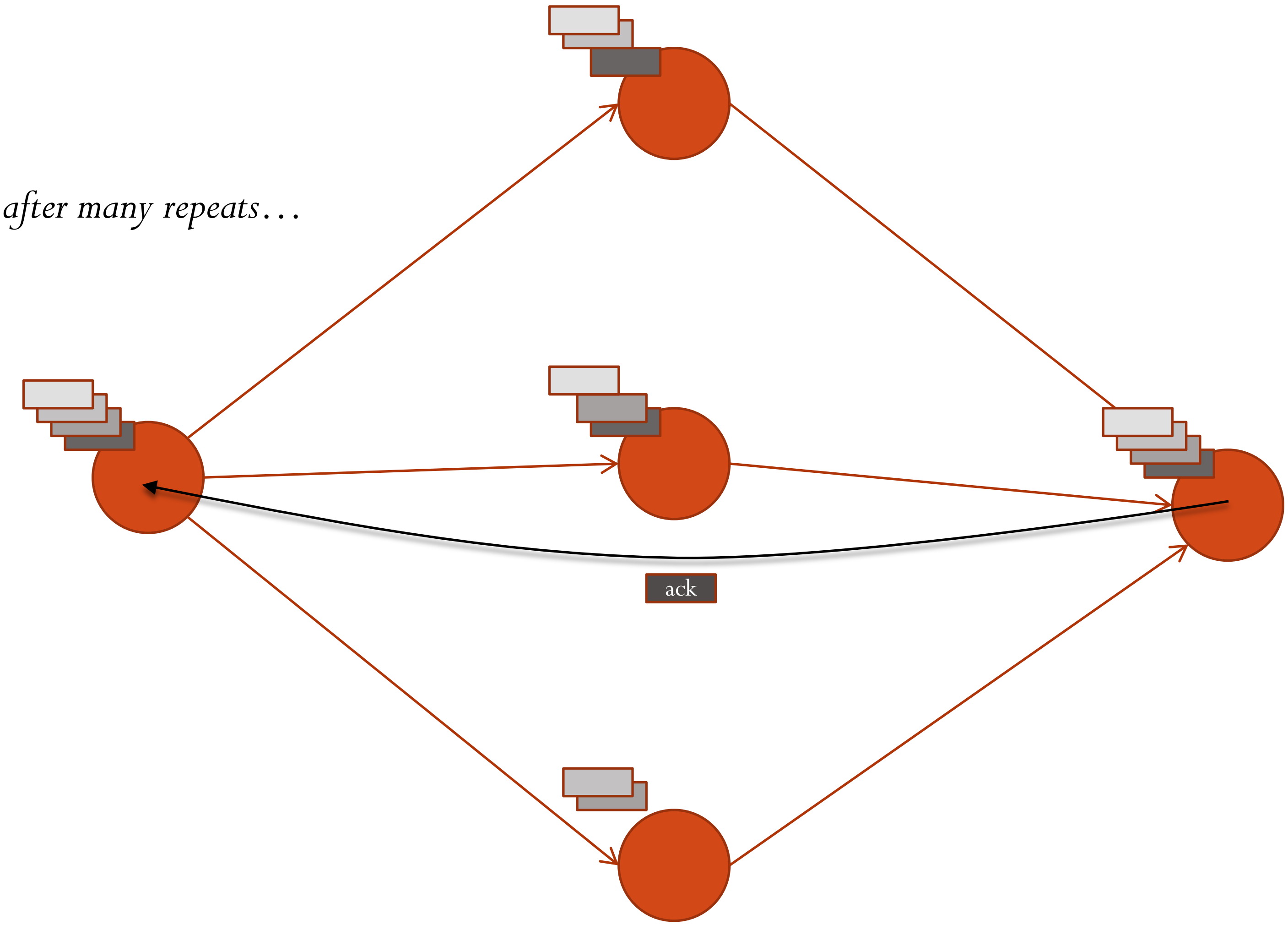


ExOR – Destination receives



ExOR – Aggregate ACK

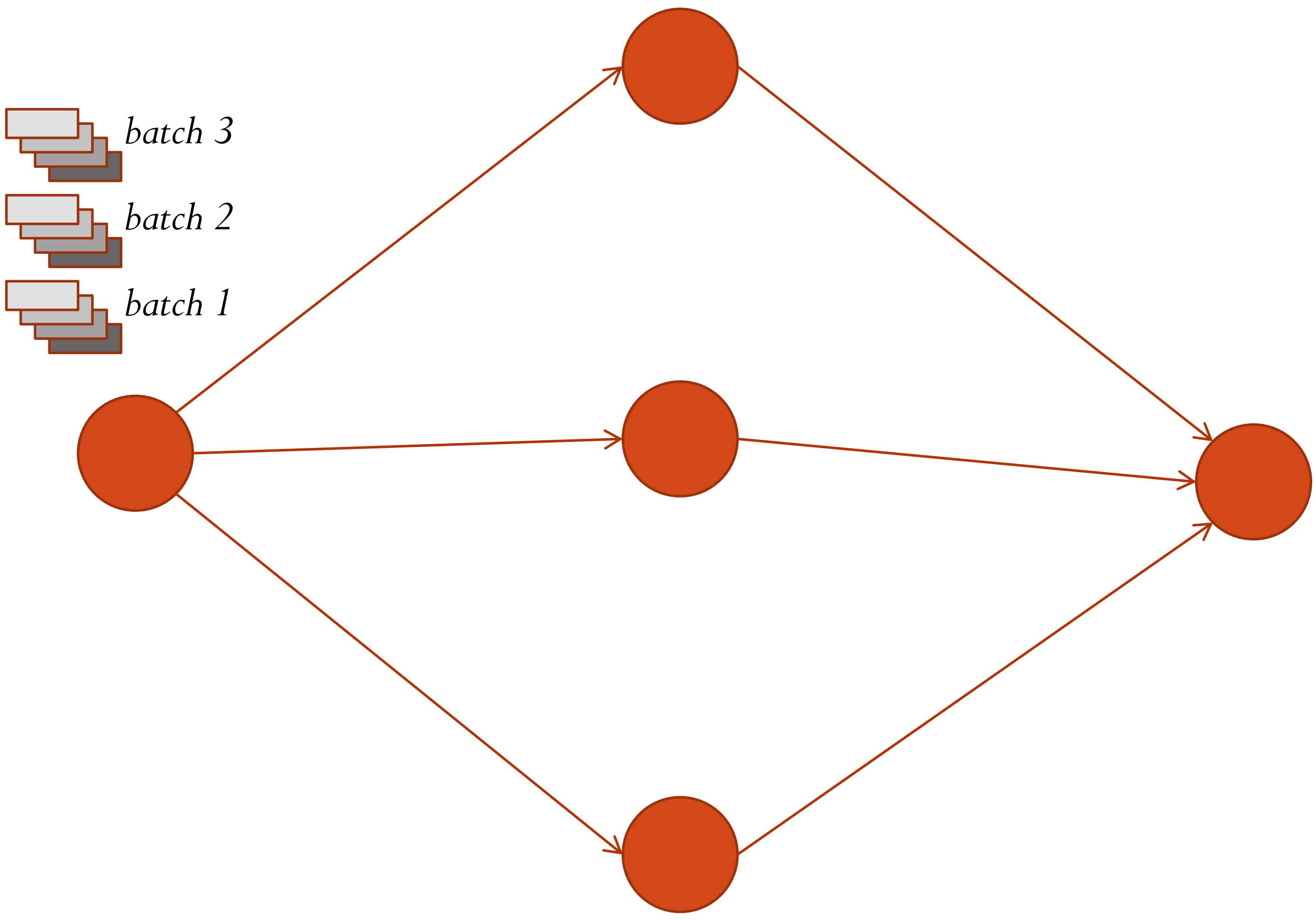
…after many repeats…



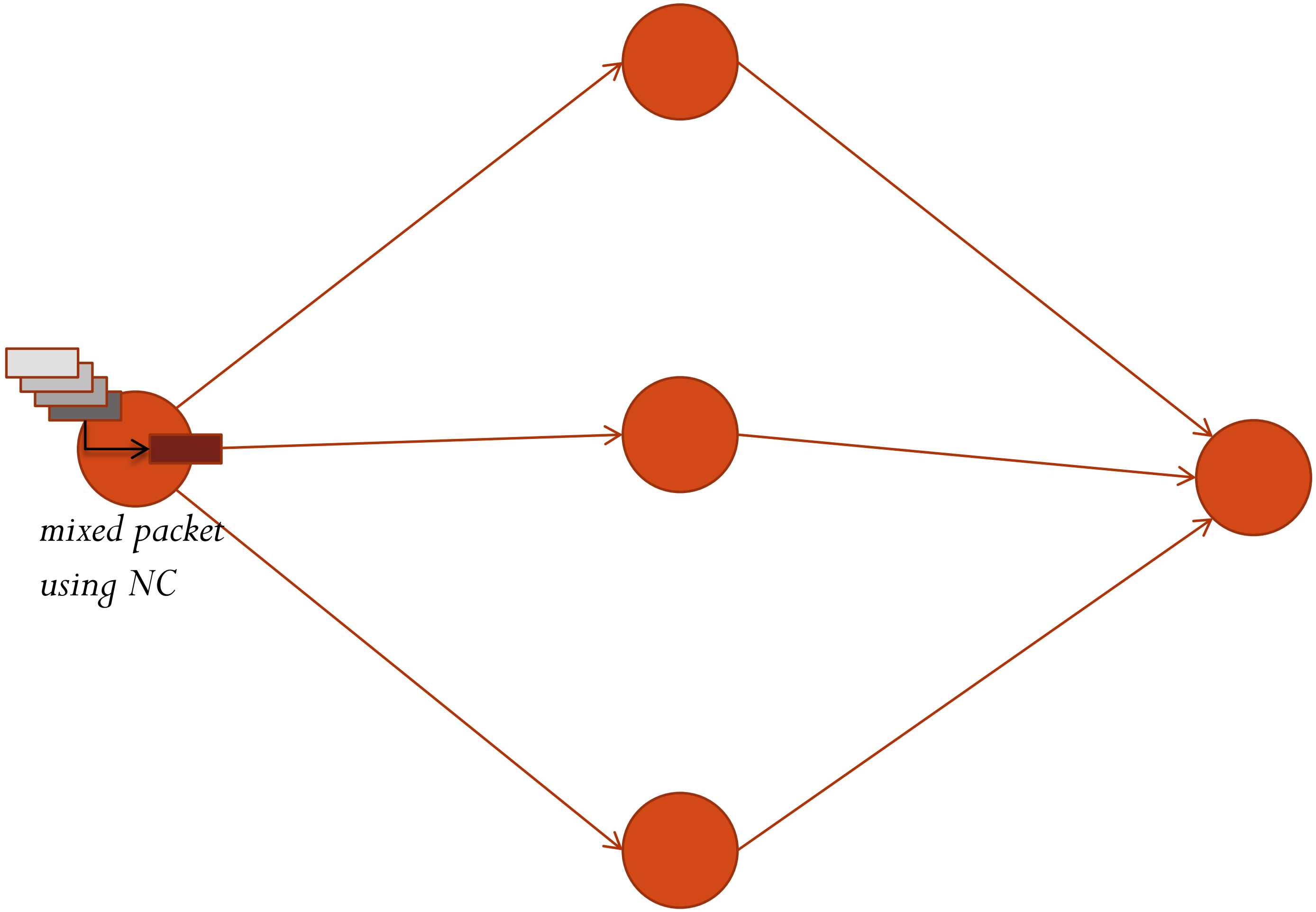
MORE (ACM SIGCOMM 2007)

- Support of multicast routing
- Uses network coding
- MAC-independent, compliant to 802.11 CSMA/CA
- Process:
  1. Source groups the packets into *batches* and randomly mixes the packets of the same batch before forwarding them
  2. Source broadcasts the network coding packets (without limitation)
  3. Each potential receiver retransmits mixing the received packets (for each receipt transmits a specified number of times)
  4. Destinations send aggregate ACKs as before
  5. Source proceeds to the following batch

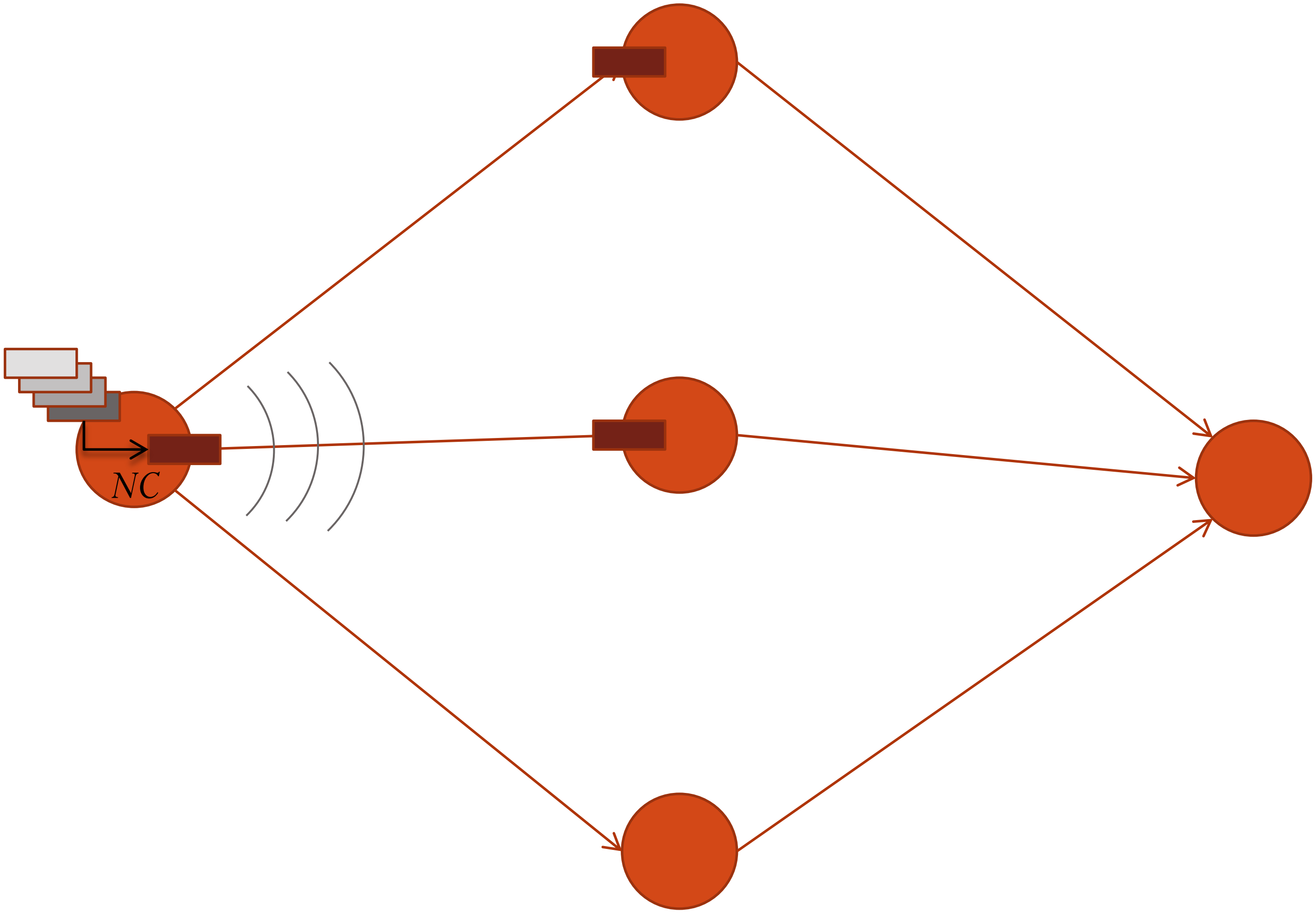
MORE – Batches separation



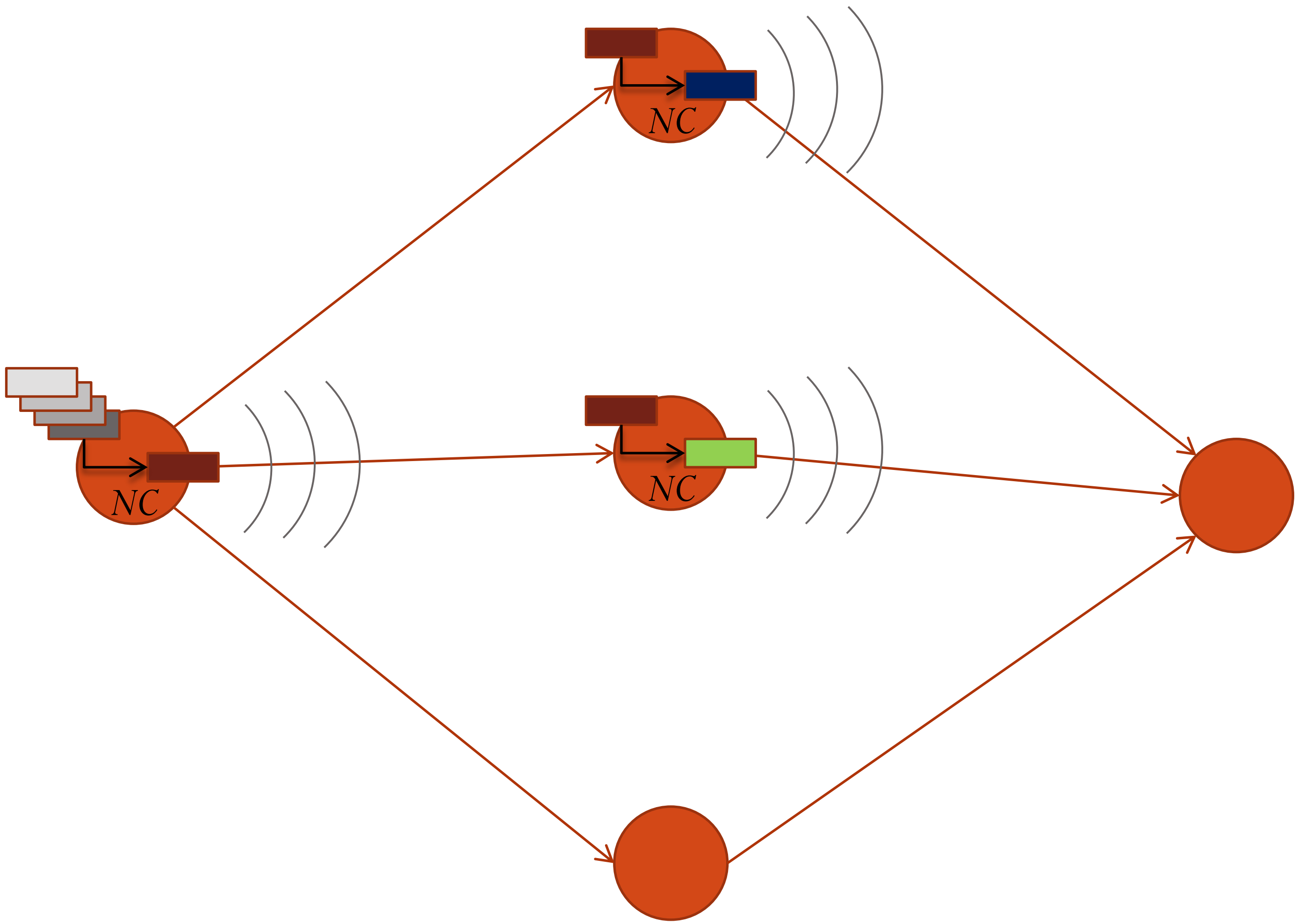
MORE – Network Coding (NC)



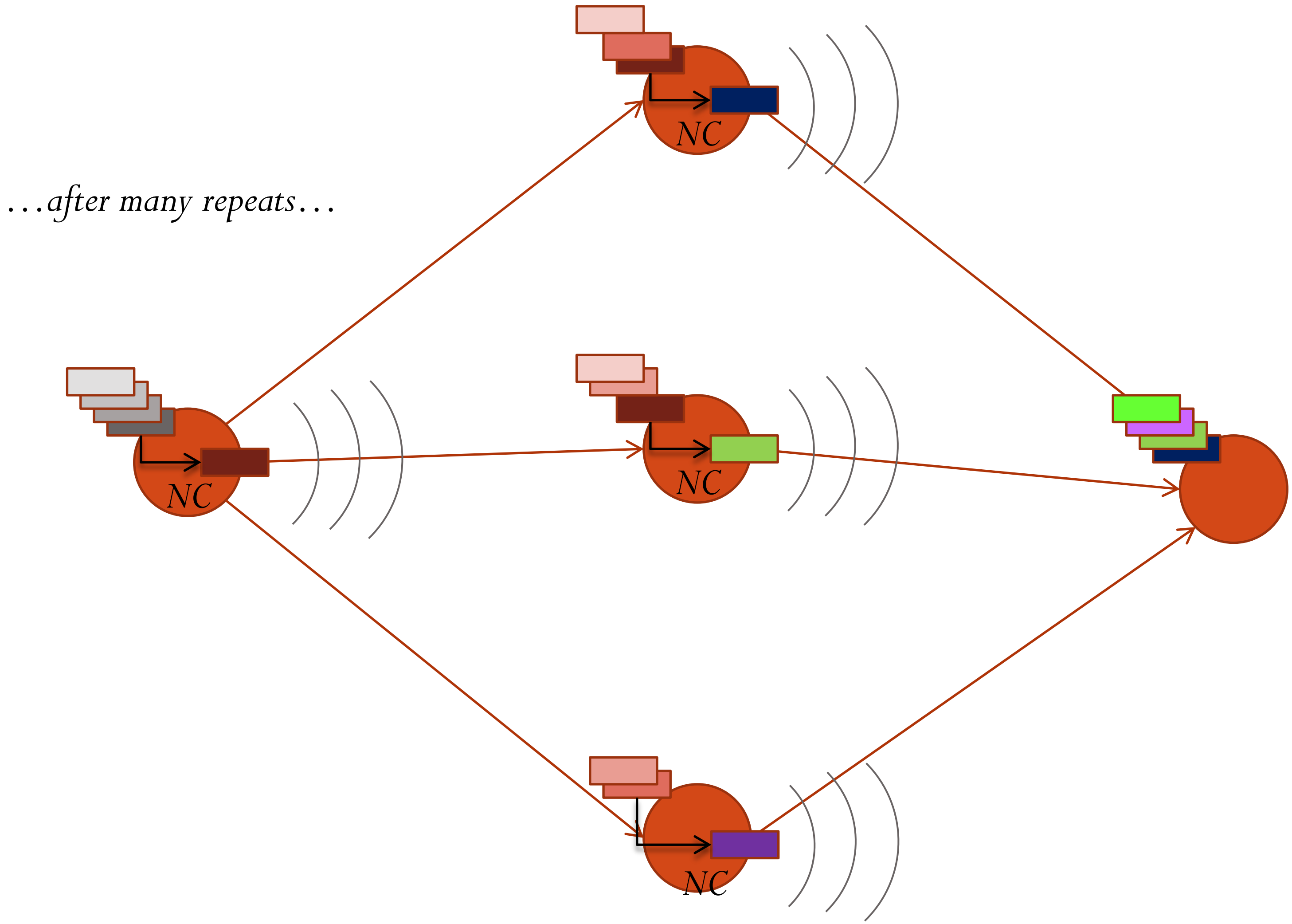
MORE – Source broadcast



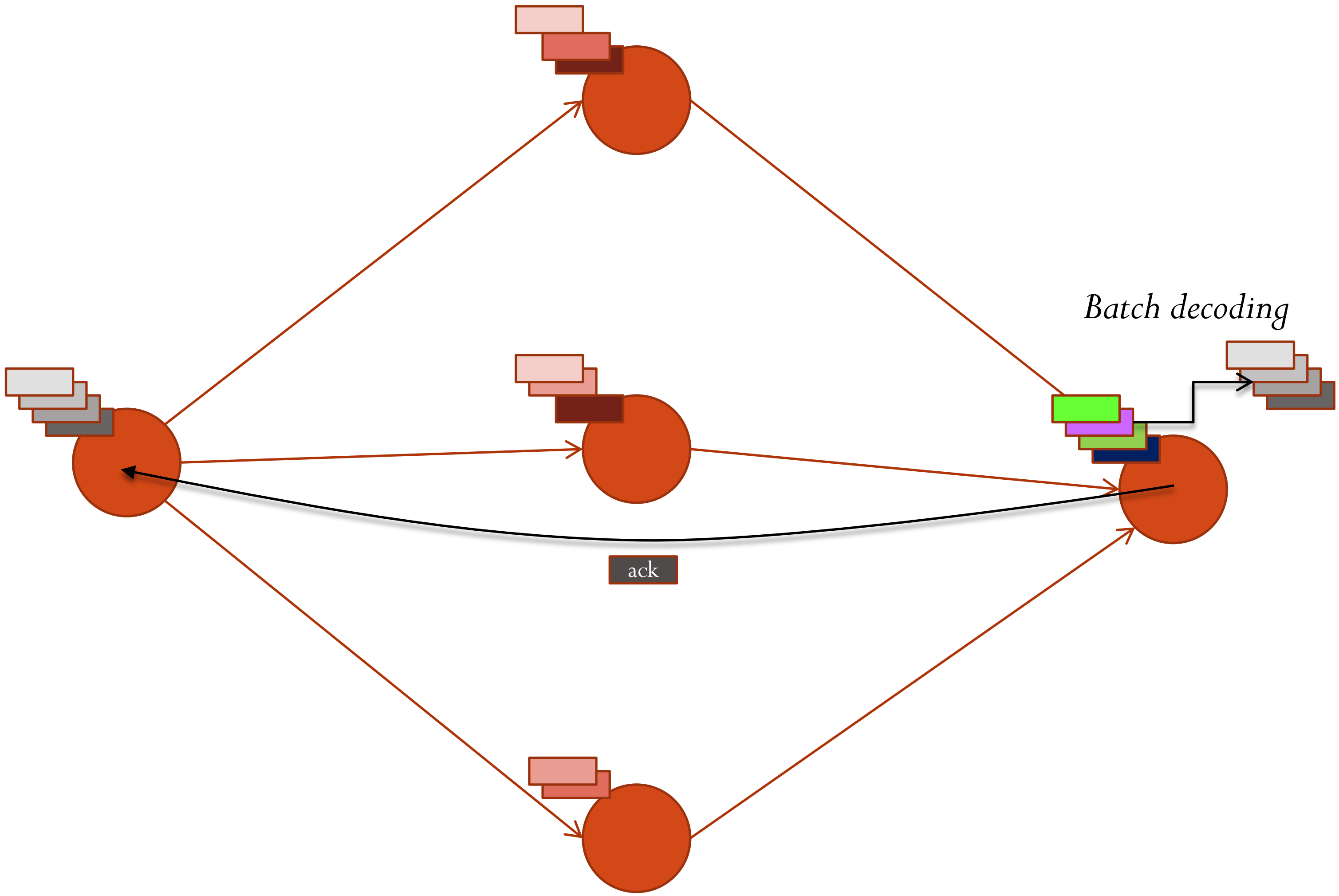
MORE – Receivers broadcast together



MORE – Destination receives



MORE – Destination decodes



Video Requirements in Routing

- **Forwarding *on-time* is of greater importance, than forwarding *reliably***
- The duration of a wireless transmission cannot be estimated
  - Occasional variations of channel conditions
  - MAC retransmissions
- In traditional routing over wireless, the duration of a forwarding process is unpredictable
  - May exceed the time constraints of a video streaming

Video Enhancements of MORE

- OR with ACK copes with similar inconvenience, making the duration of a forwarding process unpredictable
- Pacifier (IEEE/ACM Transactions on Networking 2012) addresses this weakness
  - Suggests a round-robin mechanism that enables source to move to the next batch every time that one receiver sends an ACK
  - No time guarantees again

- **Denial of the ACK mechanism enables all packets to be delivered either on-time or dropped earlier. If a forwarding process lasts more than a *slot*, source proceeds to the following batch.**

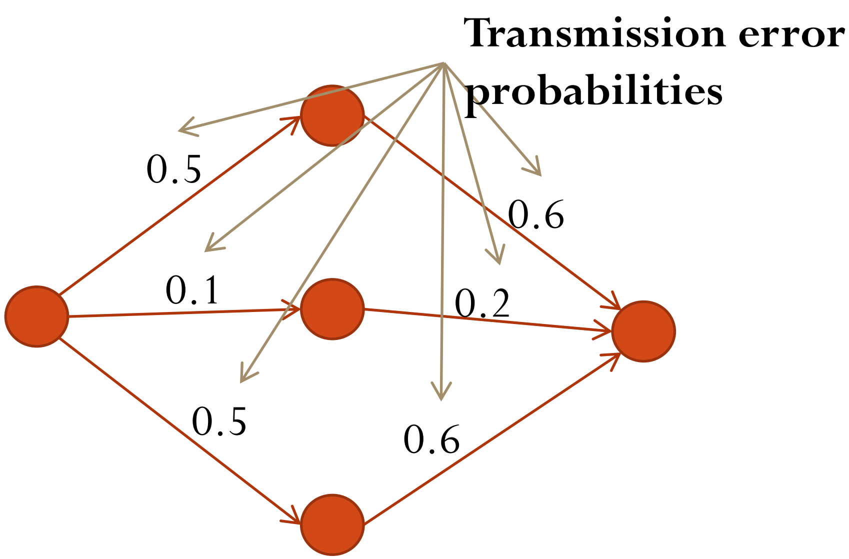
Video Enhancements of MORE

- Since there is no ACK, the number of transmissions that source and relays perform should be limited again (like ExOR)
- A *first-decode-then-transmit* policy imposes the relays to decode the whole batch and then start transmitting, reducing the contentions/collisions

- **Estimation of the number of transmissions for source and relays, is based on an algorithm that maximizes the average probability of batch reception among all destinations**

ViMOR (IEEE SECON 2014)

- Improves significantly the approach of MORE for Video streaming, following the aforementioned enhancements (and even more)
- The estimation of the transmissions of source and relays (x and y respectively) is the solution of the problem below

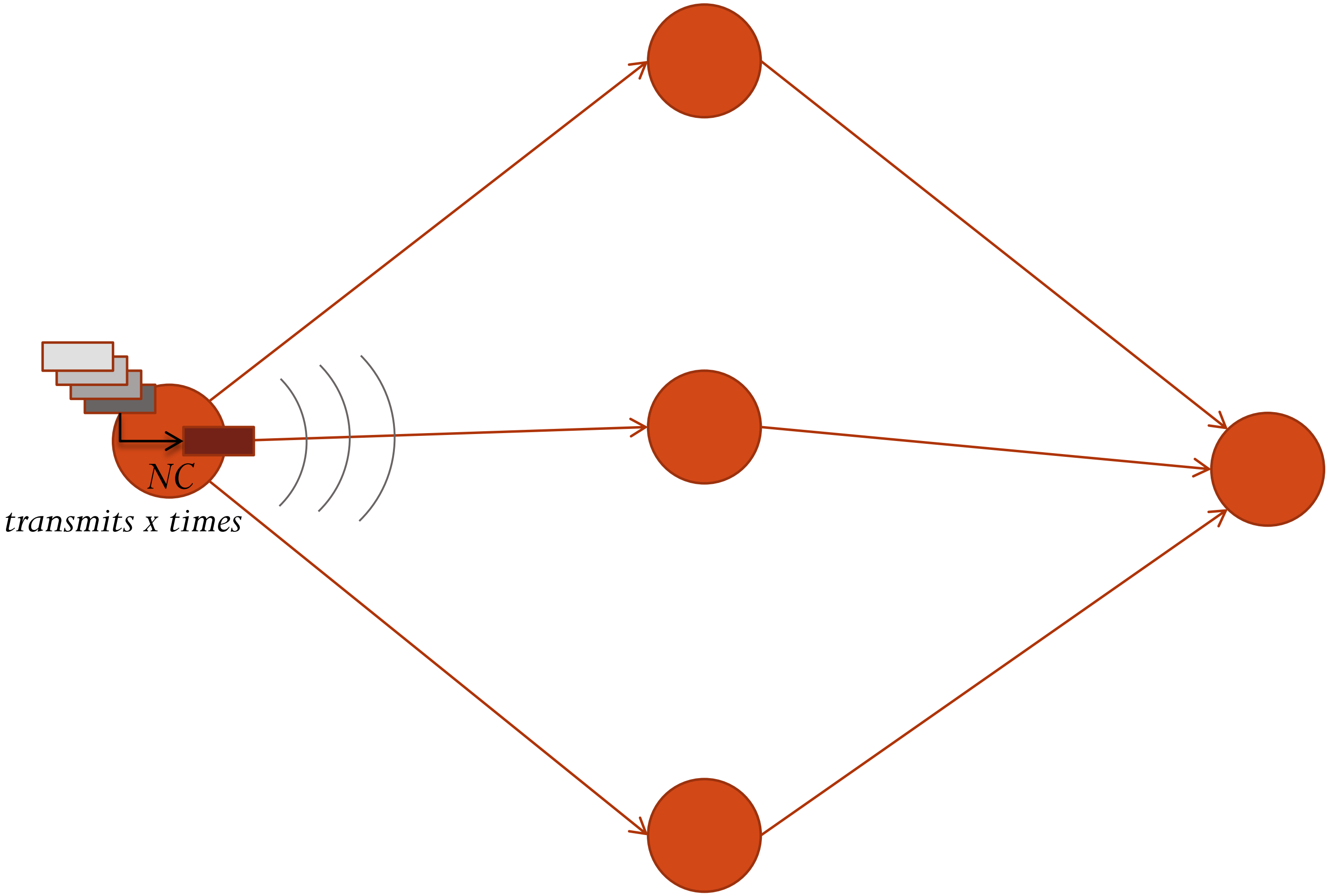


$$e_1 = 1-(1-0.5^x)(1-0.6^y)$$
$$e_2 = 1-(1-0.1^x)(1-0.2^y)$$
$$e_3 = 1-(1-0.5^x)(1-0.6^y)$$

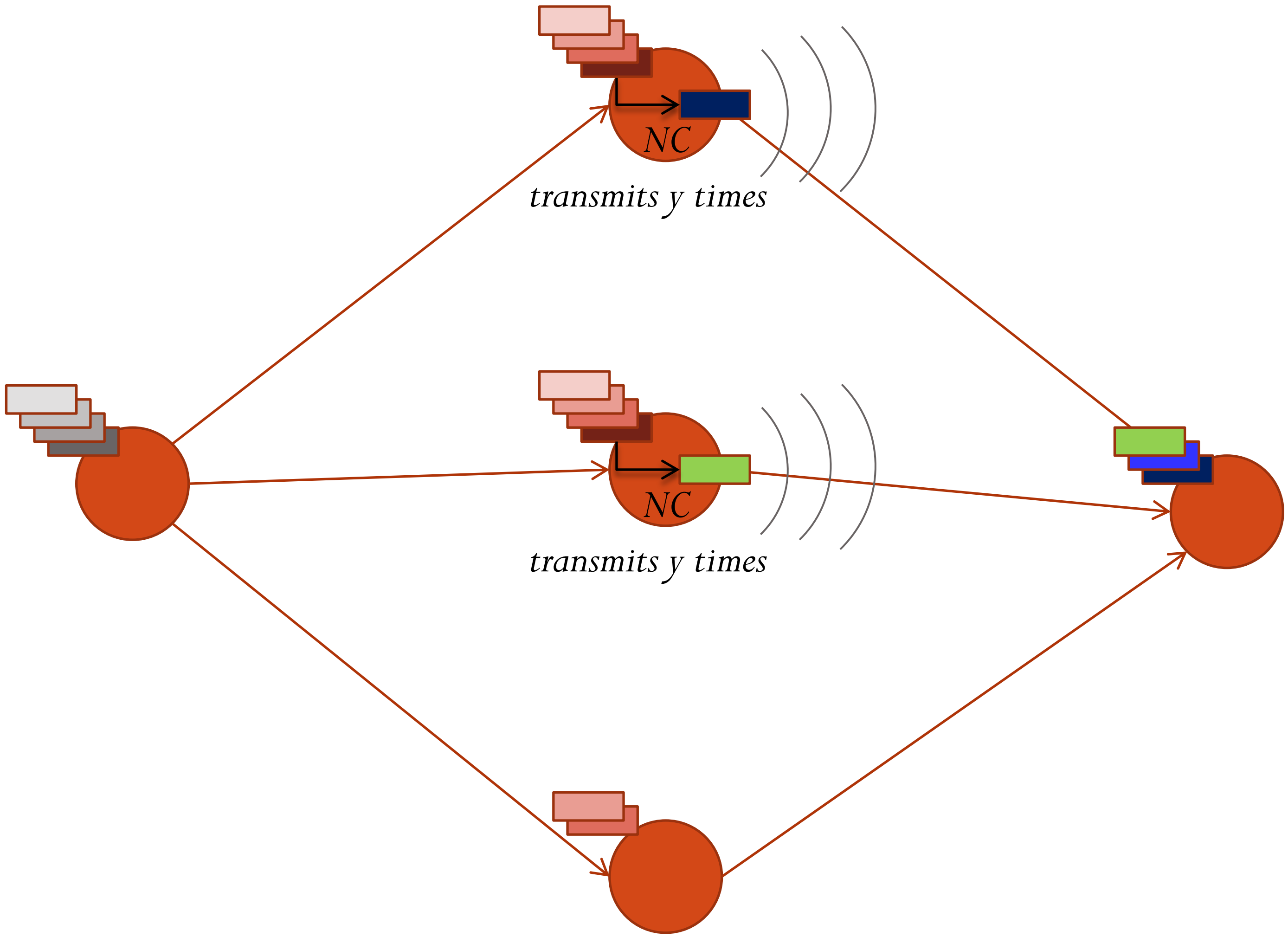
$$\max_{x,y} \quad 1 - e_1 e_2 e_3$$
$$\text{s.t. } x + 3y < c$$

c is the maximum number of transmissions could happen in a slot

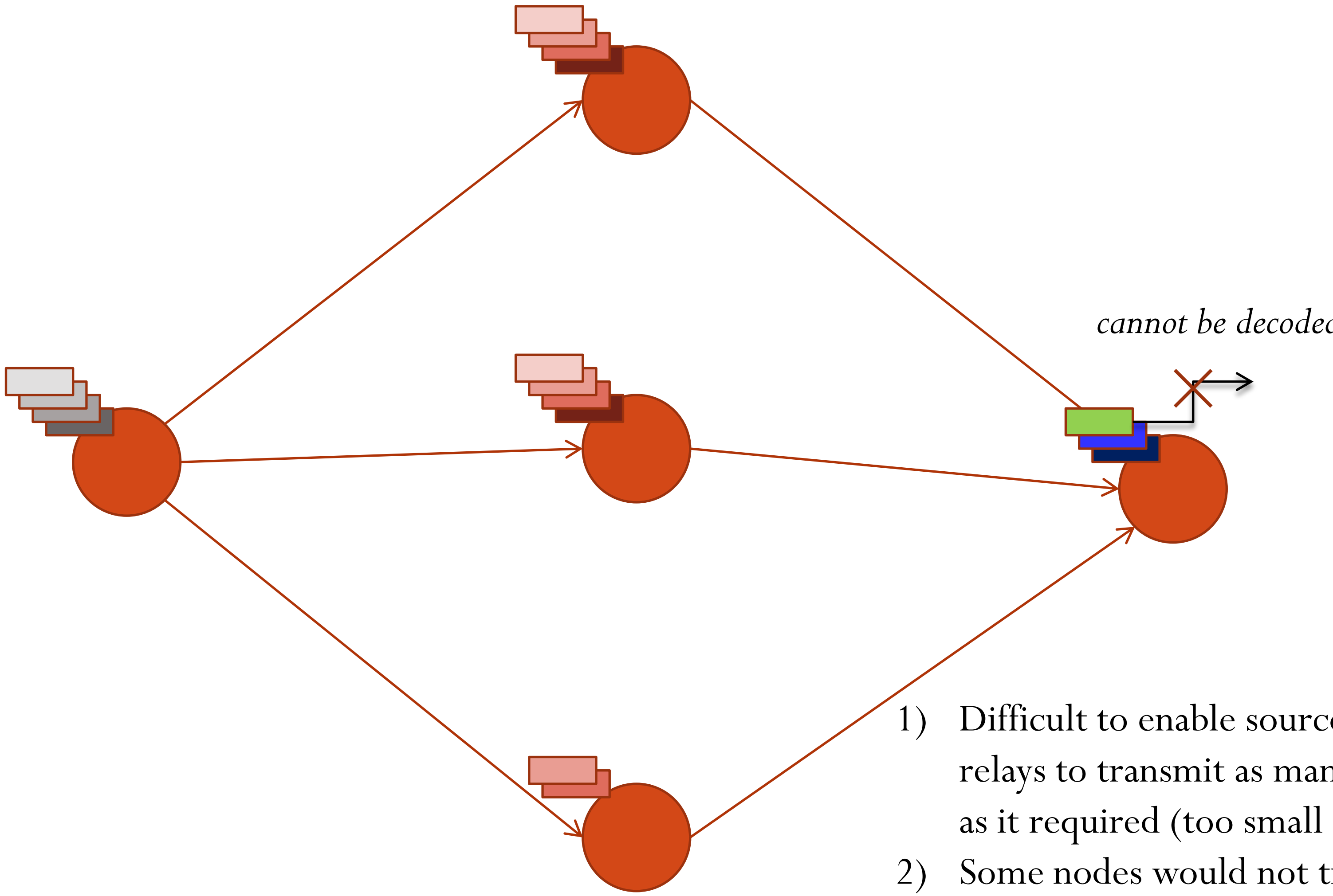
ViMOR – Source broadcasts



ViMOR – Relays decode & broadcast



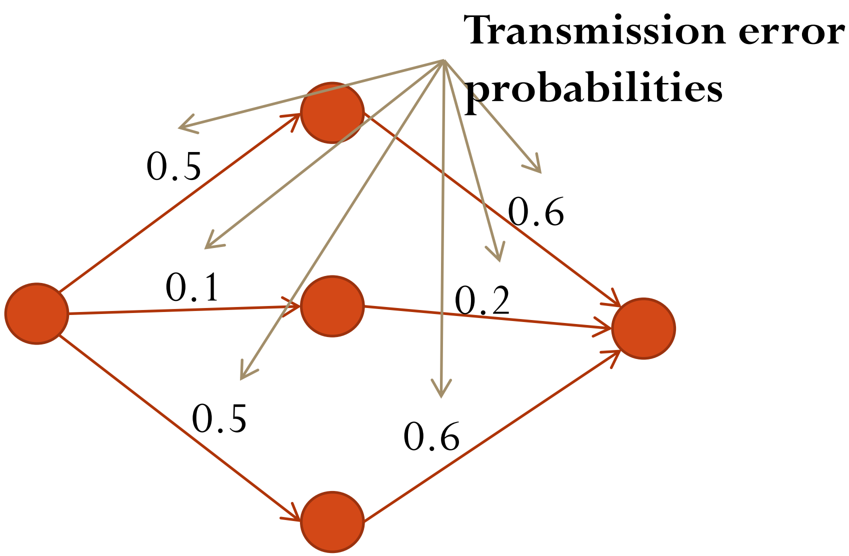
ViMOR – Destination doesn't decode



1) Difficult to enable source and 3 relays to transmit as many times as it required (too small x, y)
2) Some nodes would not transmit spending their transmission opportunities

How we improve?

- Give transmission opportunity only to the relay with the greatest probability of success



~~$e_1 = 1-(1-0.5^x)(1-0.6^y)$~~

$e_2 = 1-(1-0.1^x)(1-0.2^y)$

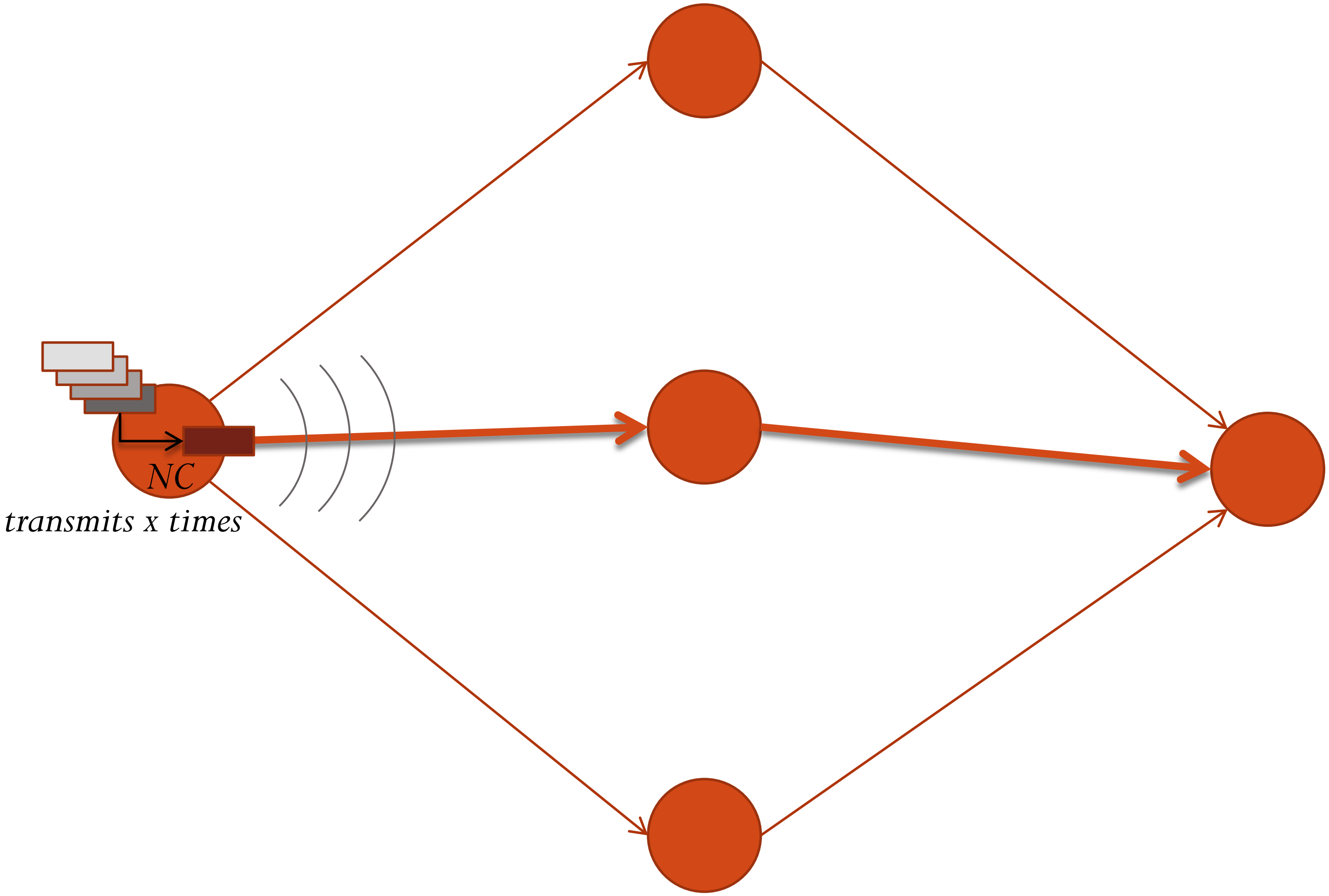
~~$e_3 = 1-(1-0.5^x)(1-0.6^y)$~~

$$\max_{x,y} \quad 1 - \cancel{e_1} e_2 \cancel{e_3}$$

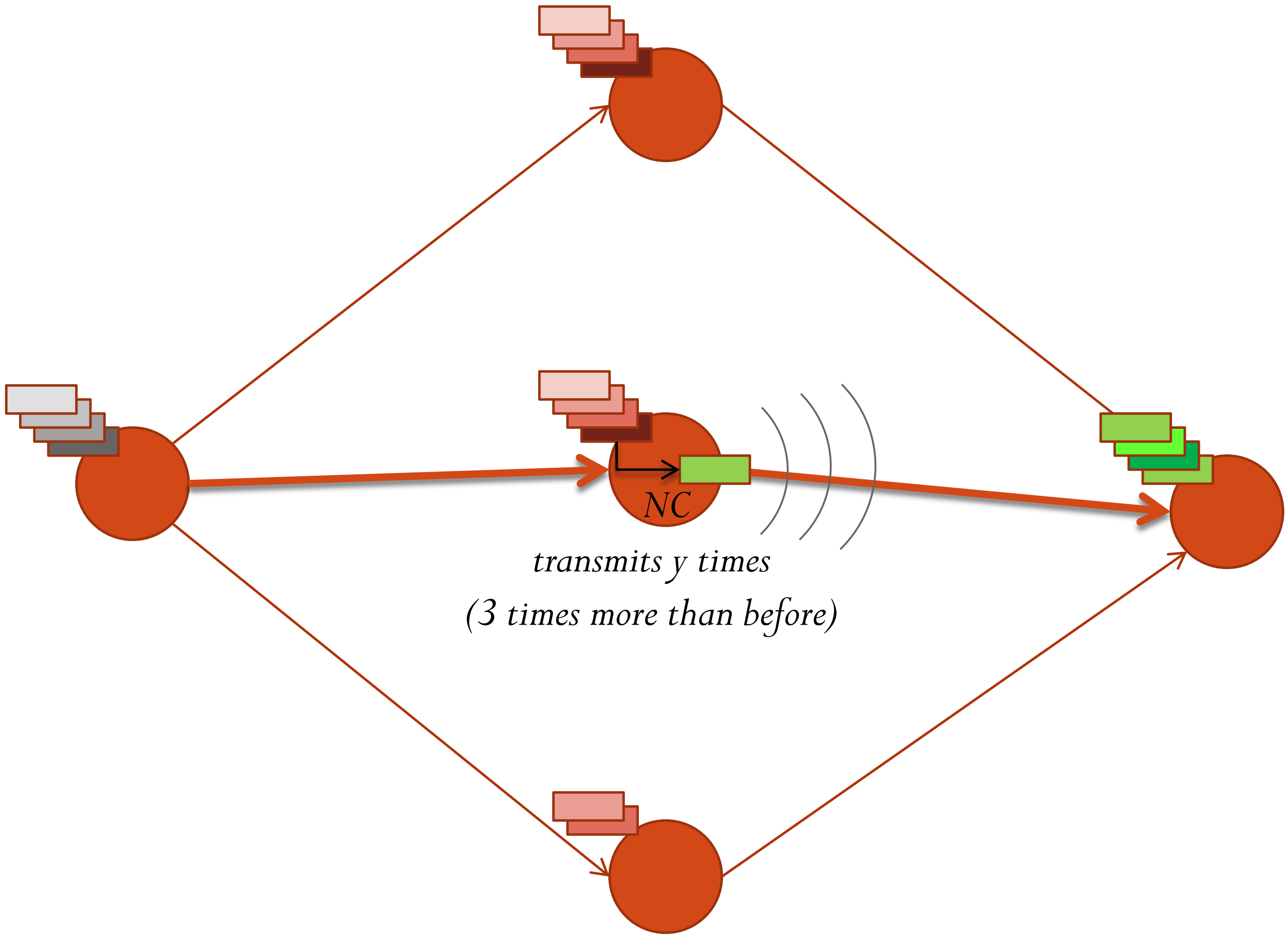
$$\text{s.t. } x + \cancel{3}y < c$$

c is the maximum number of transmissions could happen in a slot

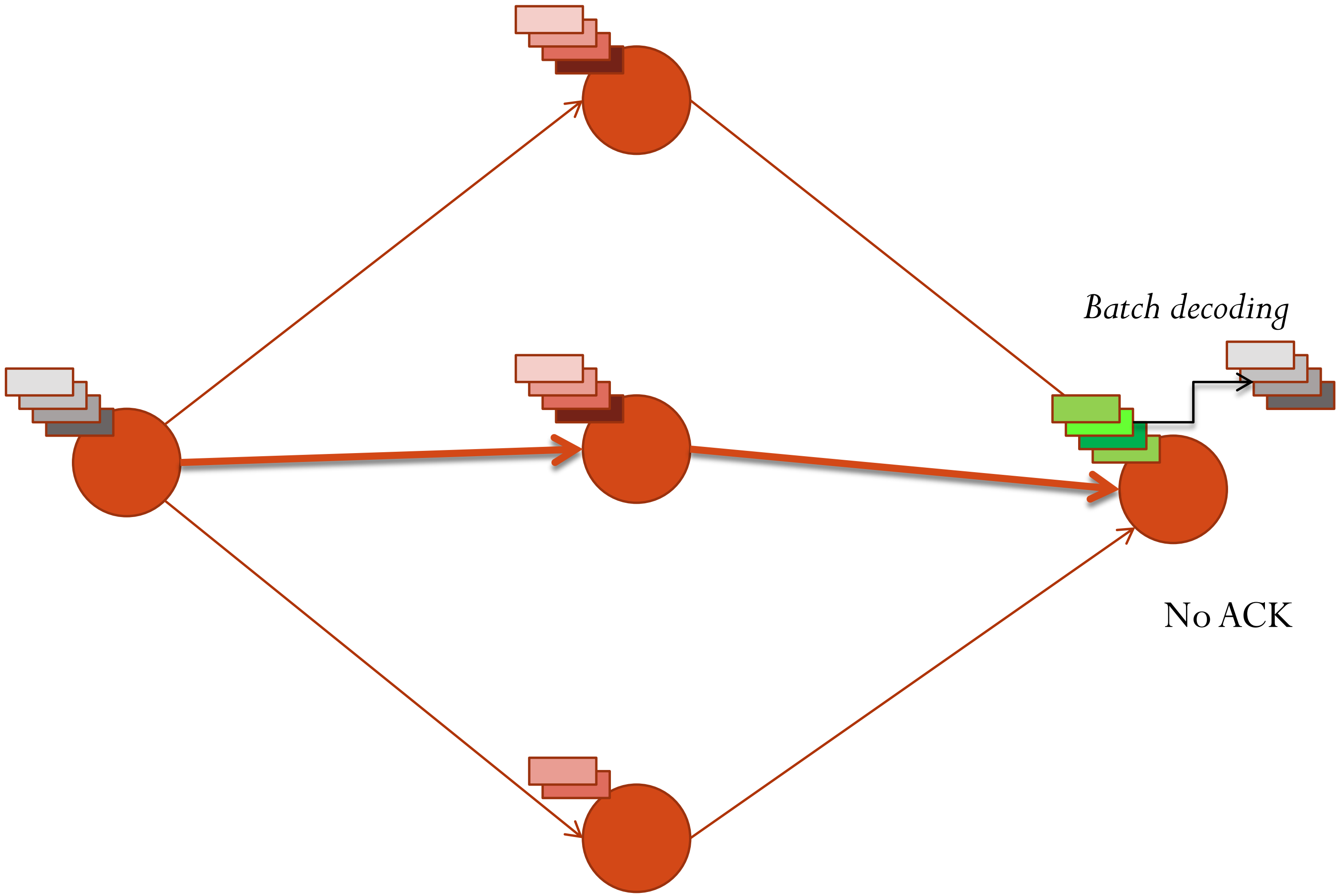
ViMOR – Source broadcasts



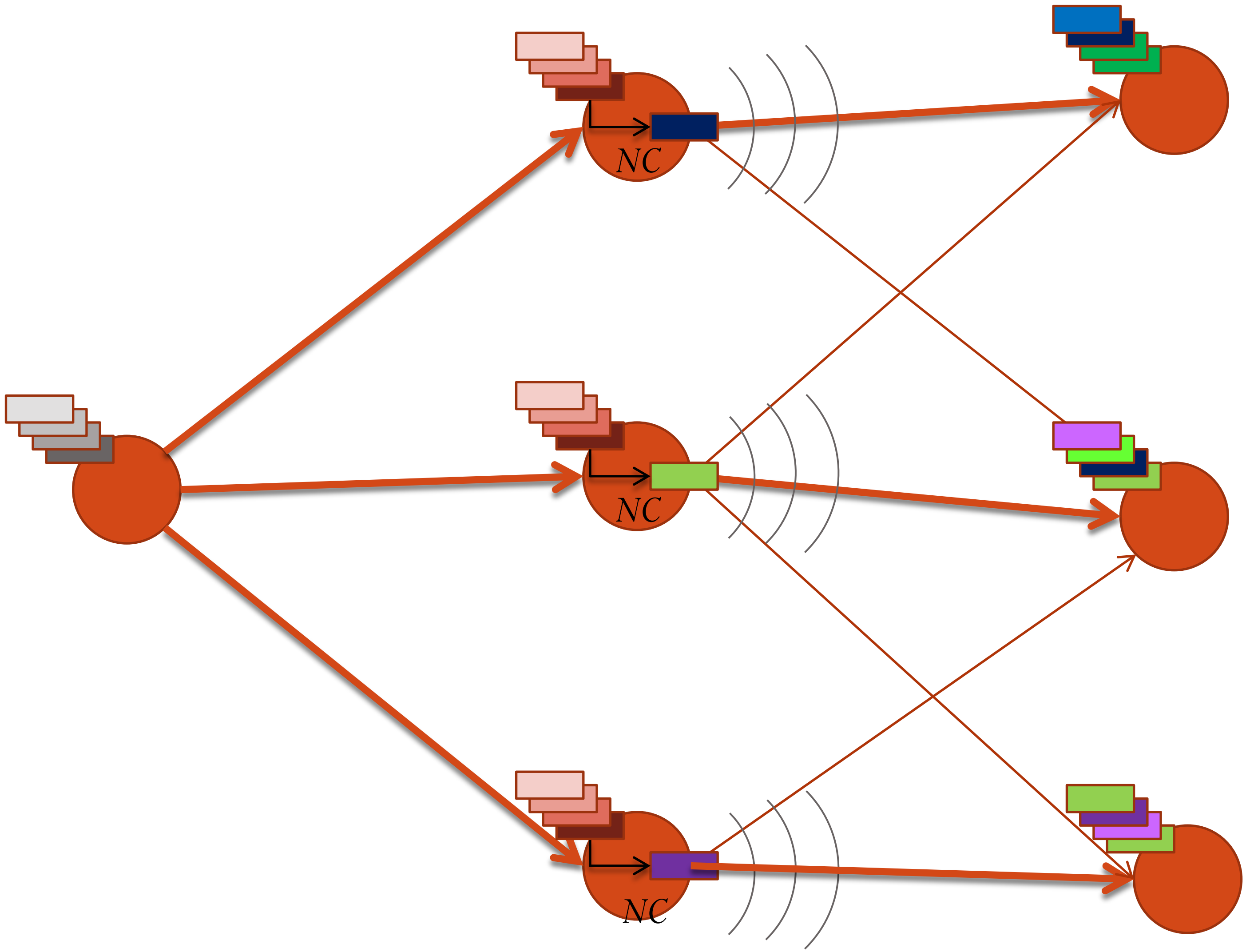
ViMOR – Relay decodes



ViMOR – Destination decodes



ViMOR – Diversity in Multicast



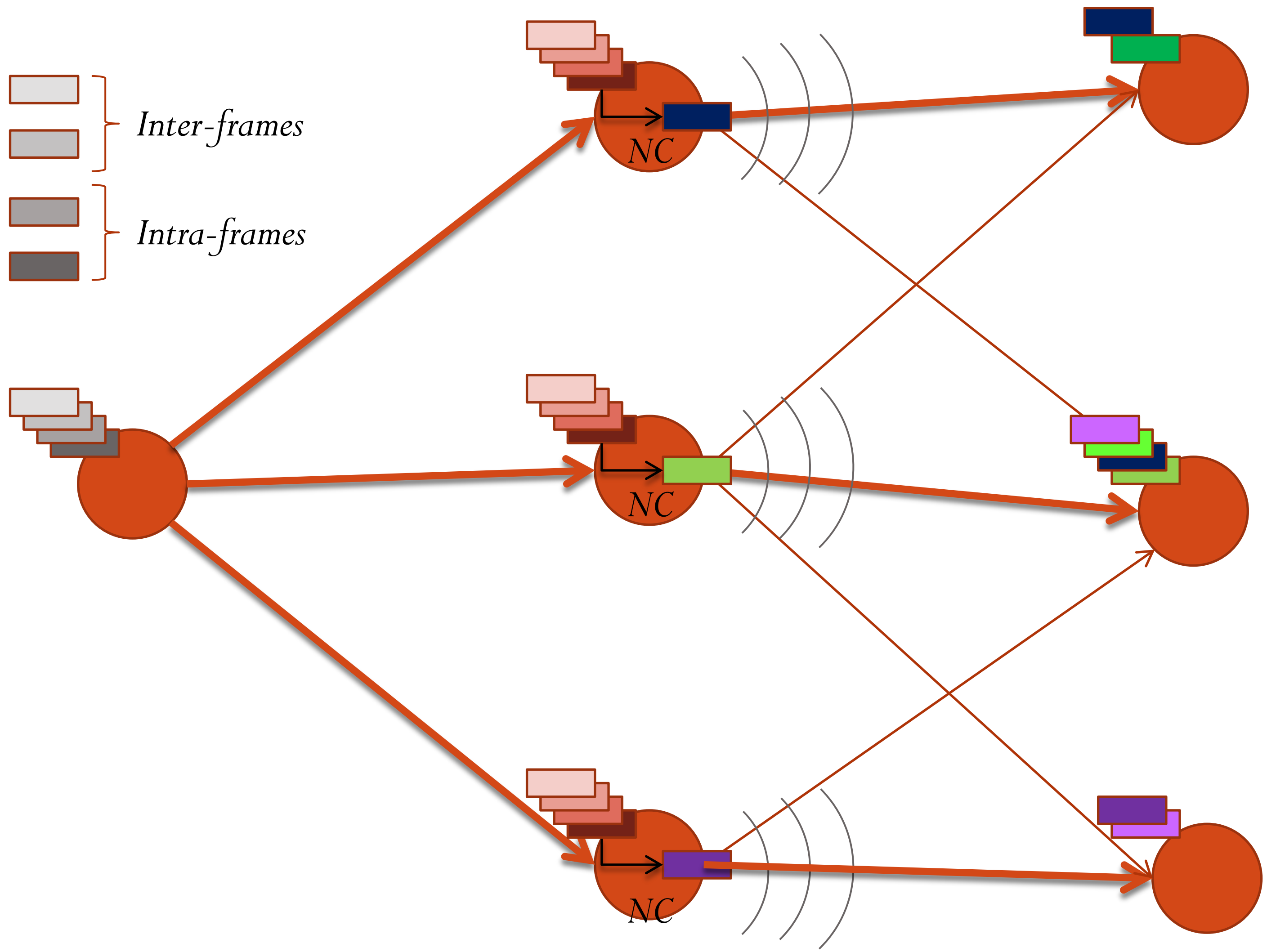
Improving even more…

- OR-PLC (IEEE Globecom 2010) uses Priority Linear Coding (PLC) in NC enabling the decoding of a subset of the batch packets, when the decoding of the whole batch is infeasible.

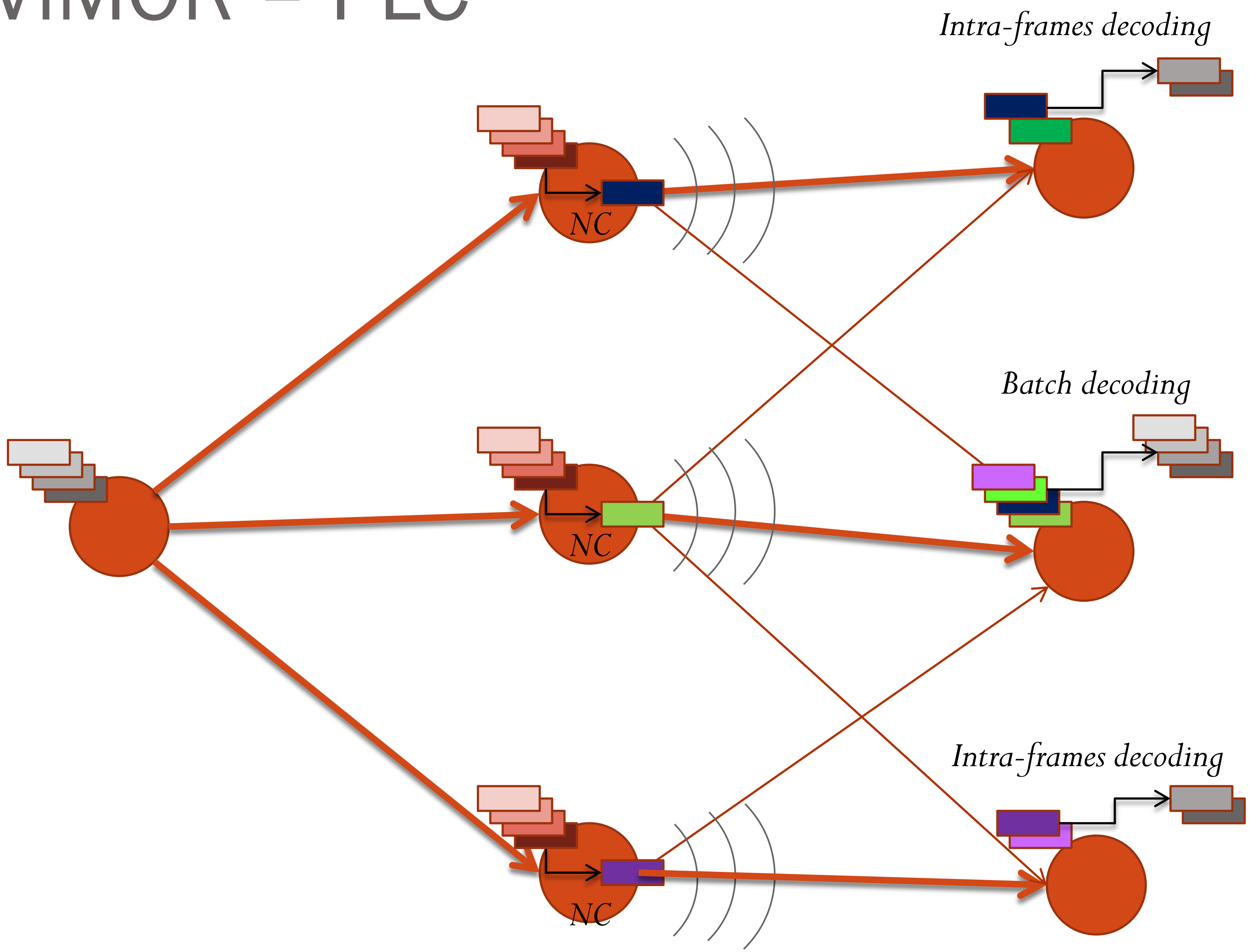
- In video streaming, the retrieval of the intra-frames only, even if we loose the inter-frames, is something affordable.

- **Classification and prioritization of the video packets, adopting PLC.**

ViMOR – PLC

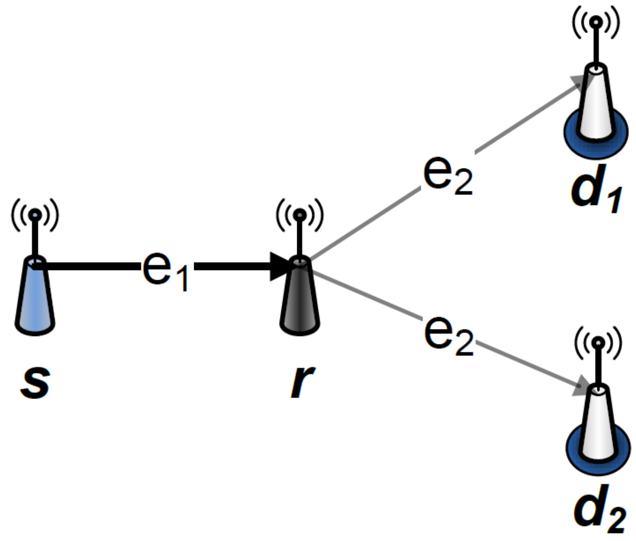


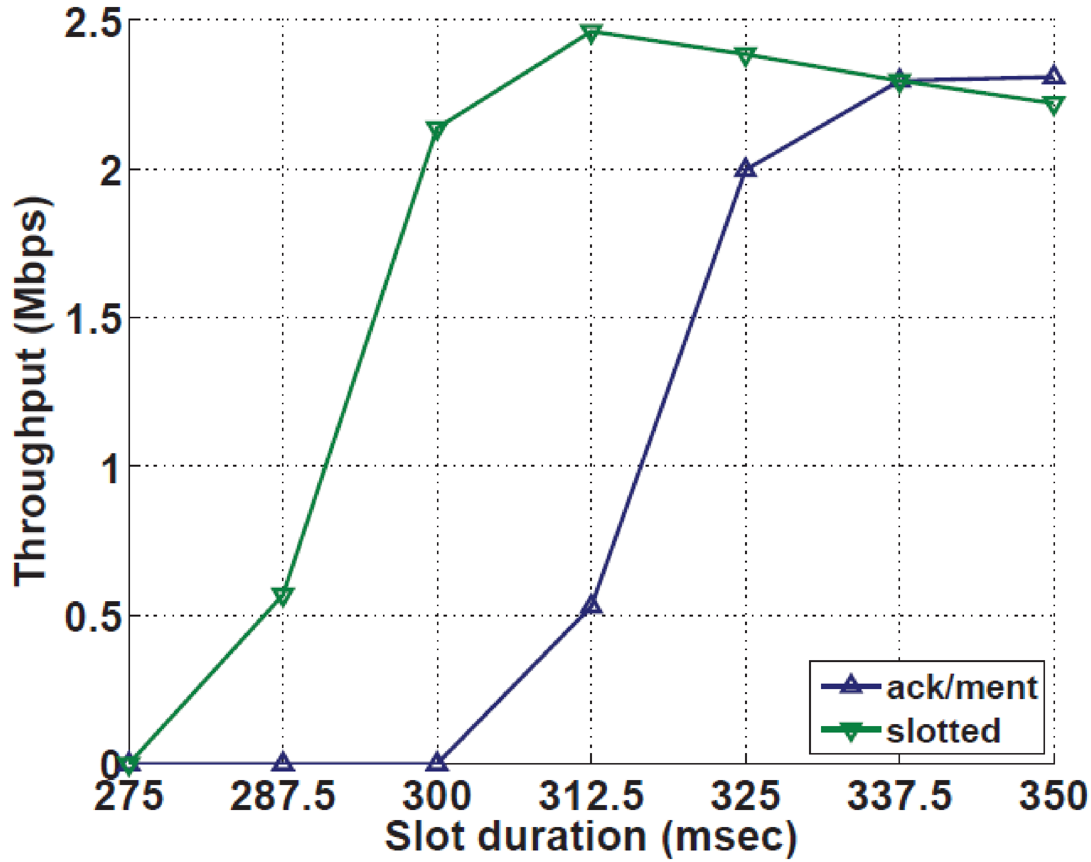
ViMOR – PLC


Intra-frames decoding
NC
Batch decoding
NC
Intra-frames decoding
NC

Experimentation results

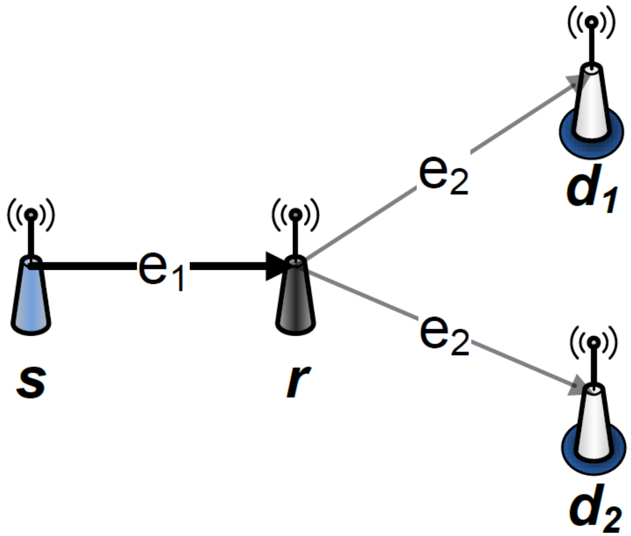
Experimenting in Denial of ack

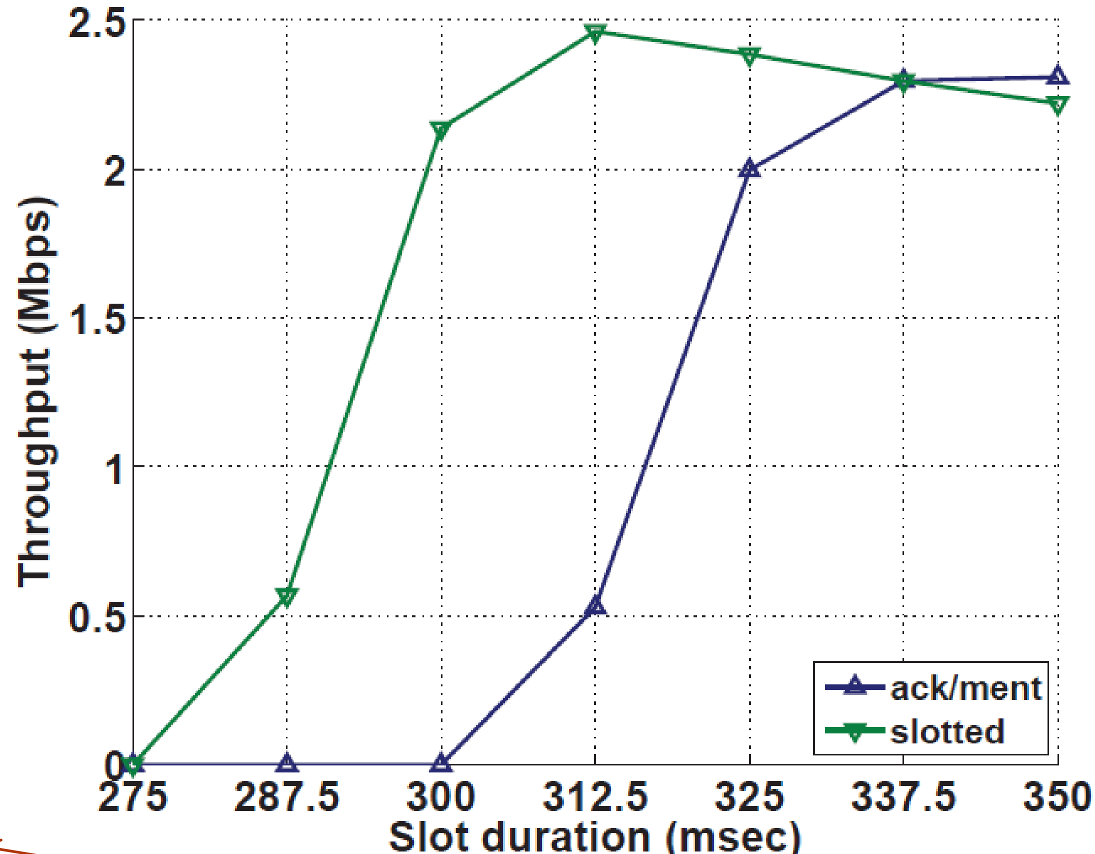




(a) The slotted mechanism of ViMOR compared to the acknowledgment mechanism of MORE for $k = 64$ and $e_1 = e_2 \approx 0.001$.

Experimenting in Denial of ack

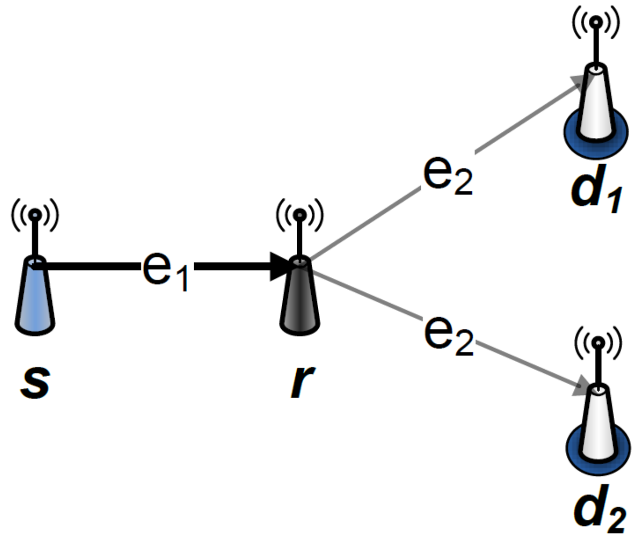


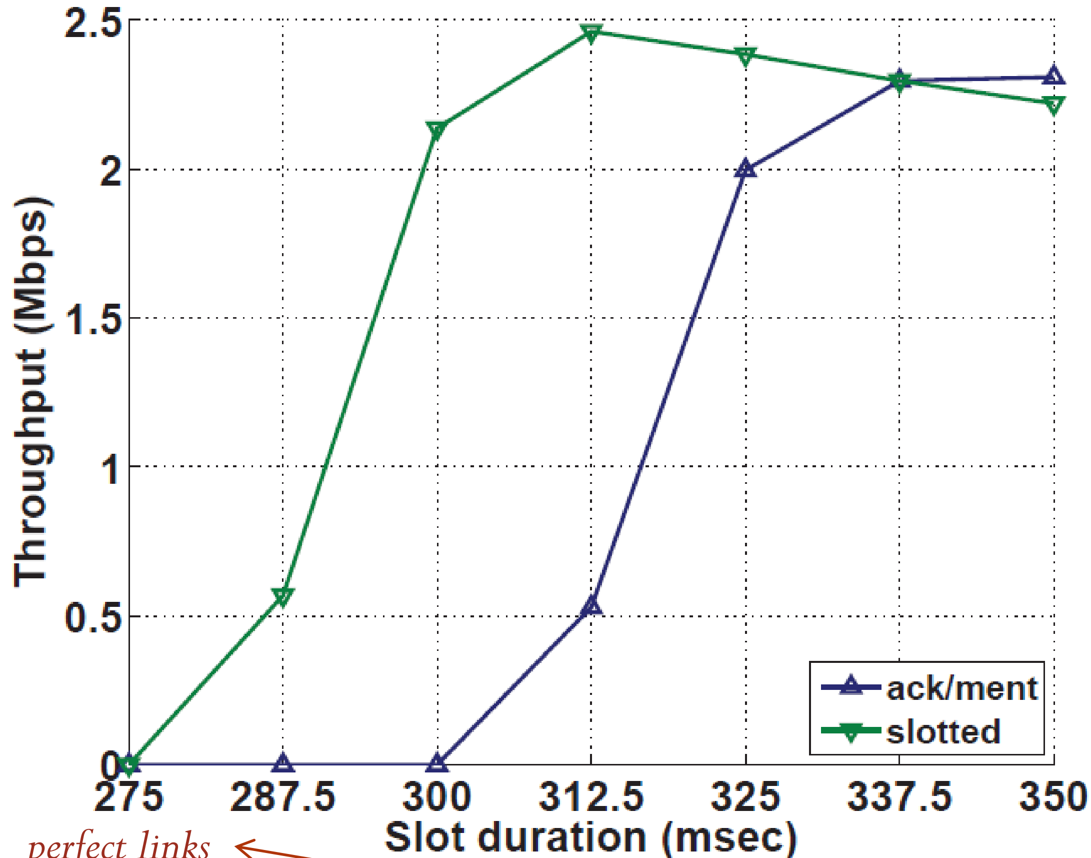


batch size

(a) The slotted mechanism of ViMOR compared to the acknowledgment mechanism of MORE for $k = 64$ and $e_1 = e_2 \approx 0.001$.

Experimenting in Denial of ack

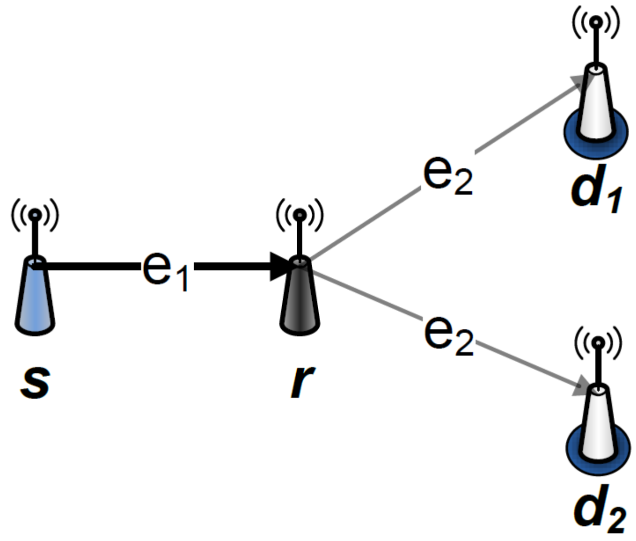


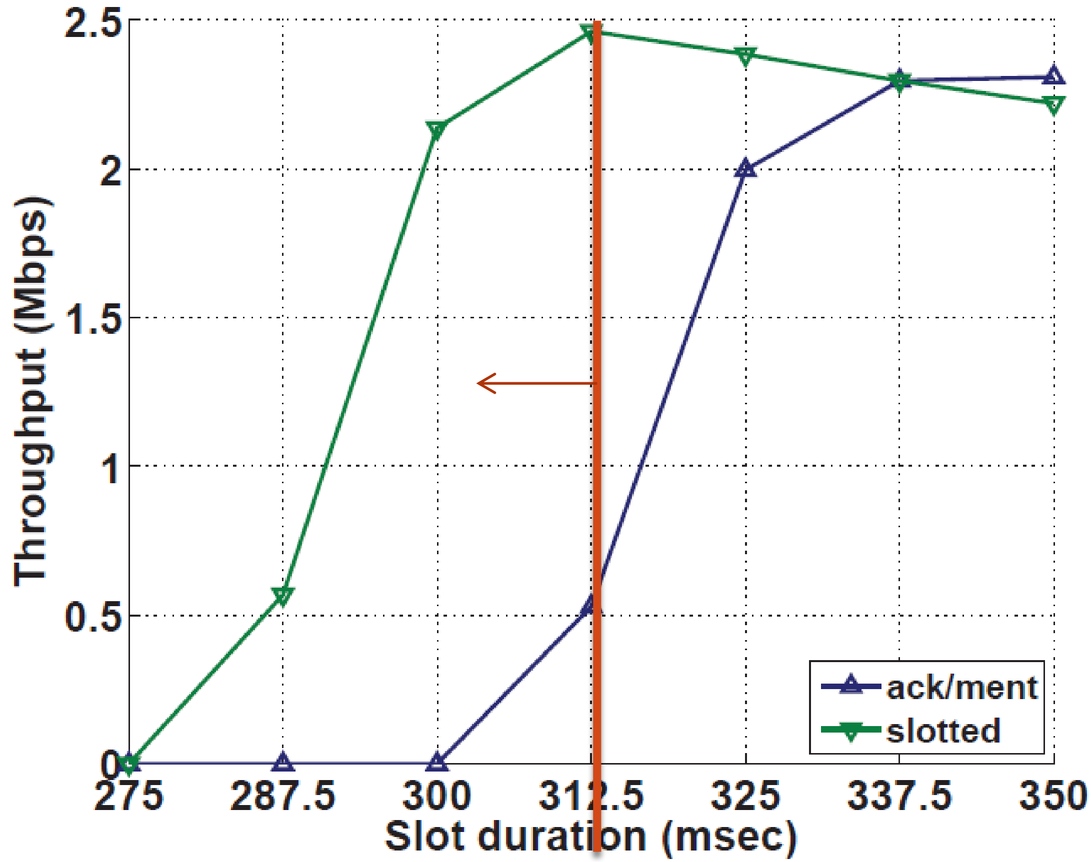


perfect links

(a) The slotted mechanism of ViMOR compared to the acknowledgment mechanism of MORE for $k = 64$ and $e_1 = e_2 \approx 0.001$.

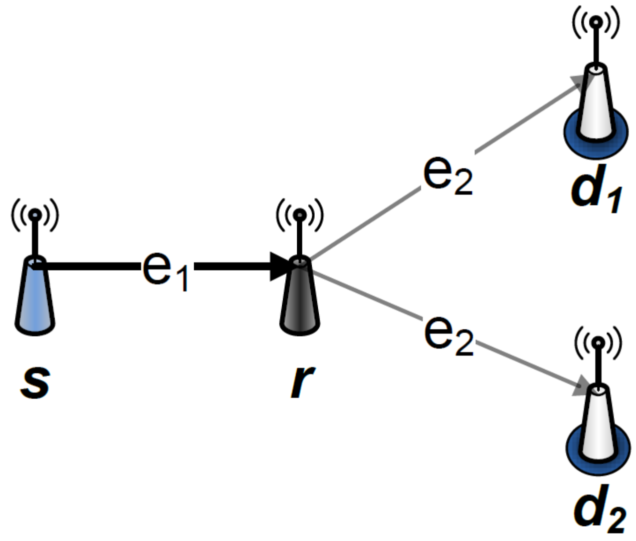
Experimenting in Denial of ack

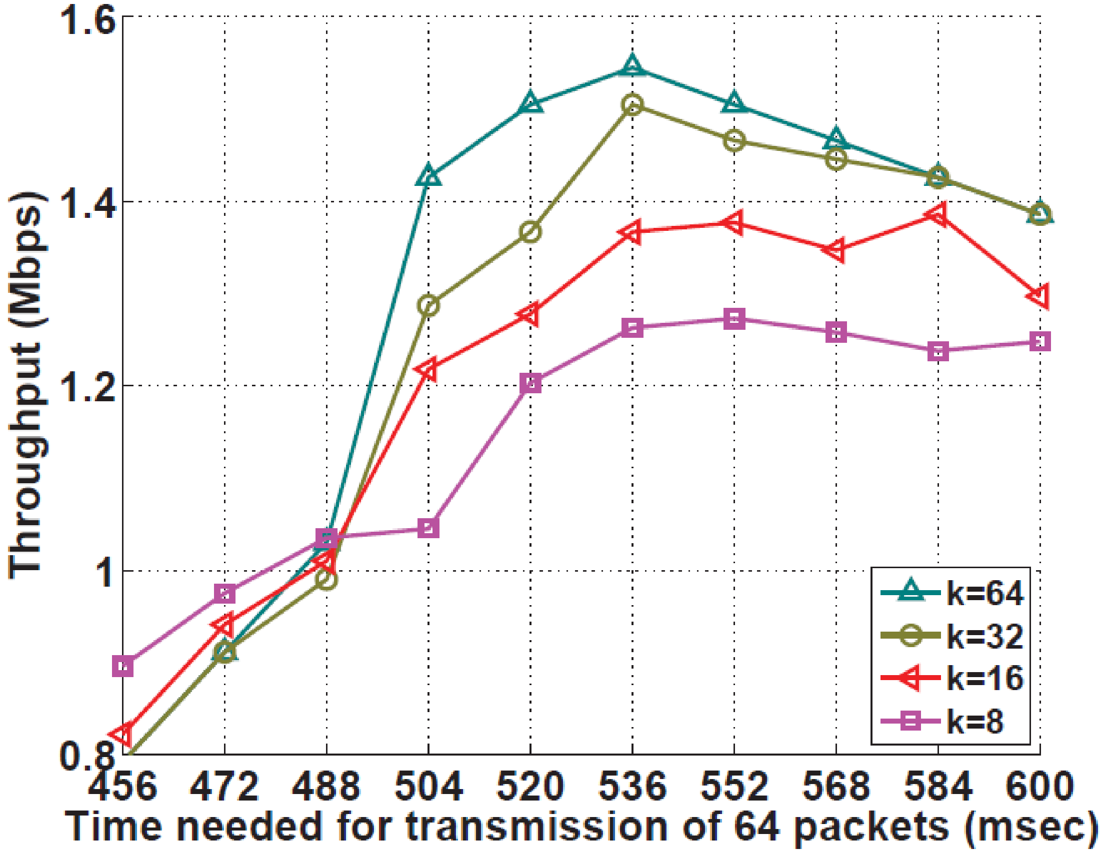




(a) The slotted mechanism of ViMOR compared to the acknowledgment mechanism of MORE for $k = 64$ and $e_1 = e_2 \approx 0.001$.

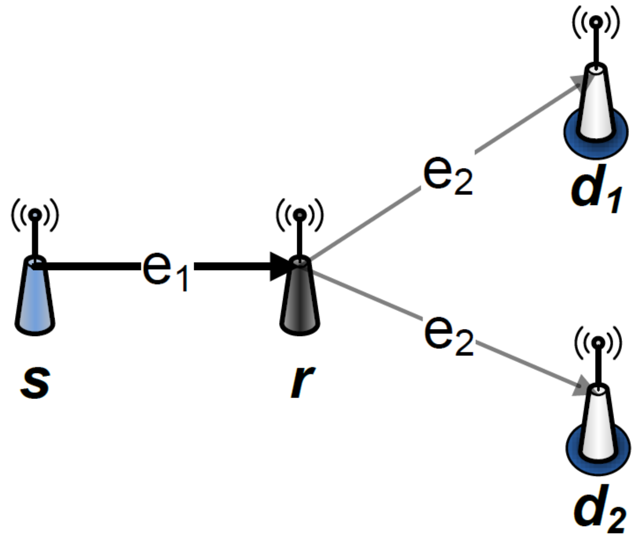
Experimenting in batch size (k)

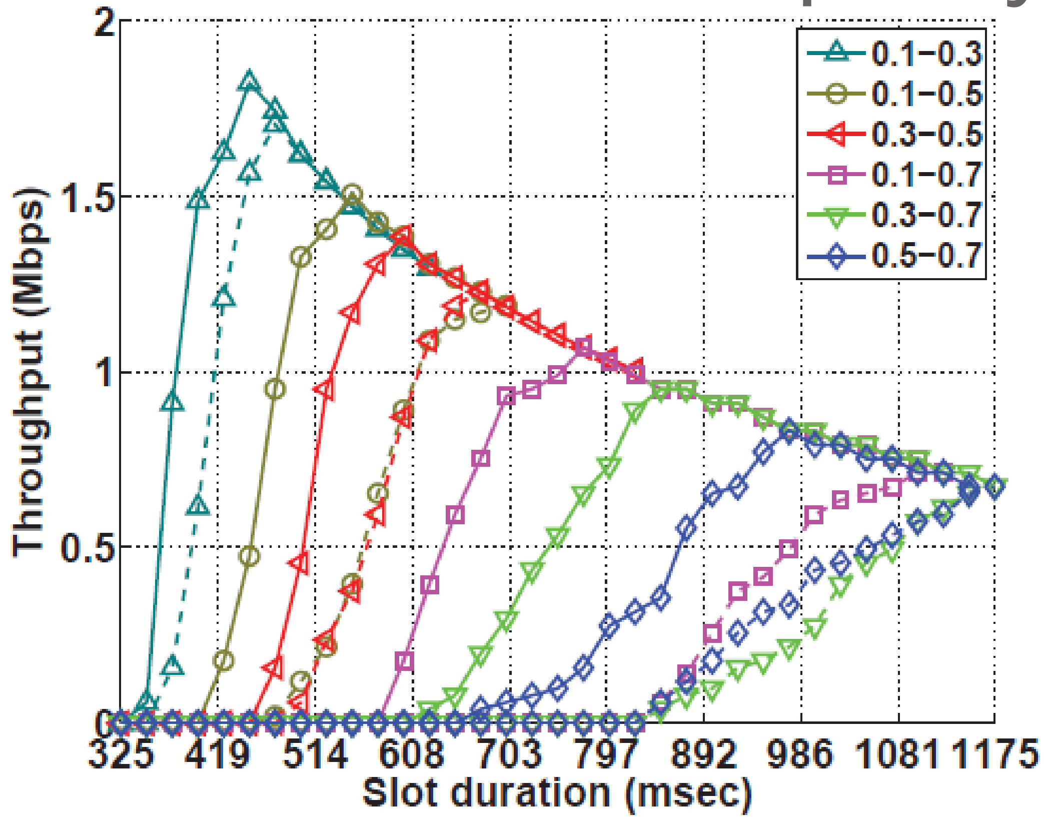




(b) The VIMOR's credit assignment performance for $k = 8, 16, 32, 64$ and $e_1 = 0.1$ and $e_2 = 0.5$.

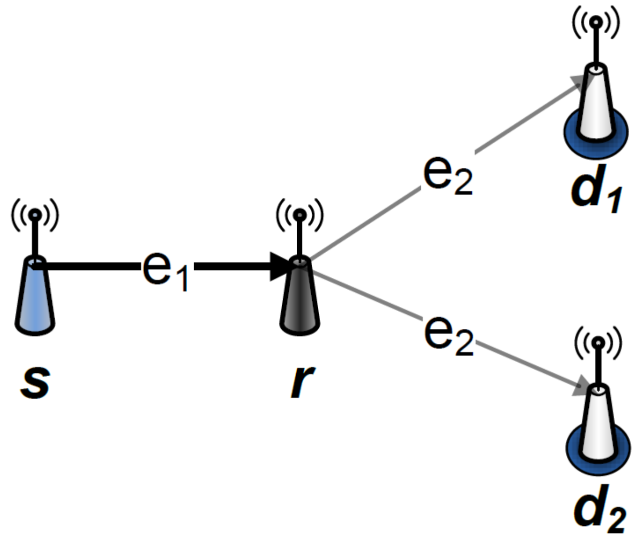
Experimenting in transmissions policy

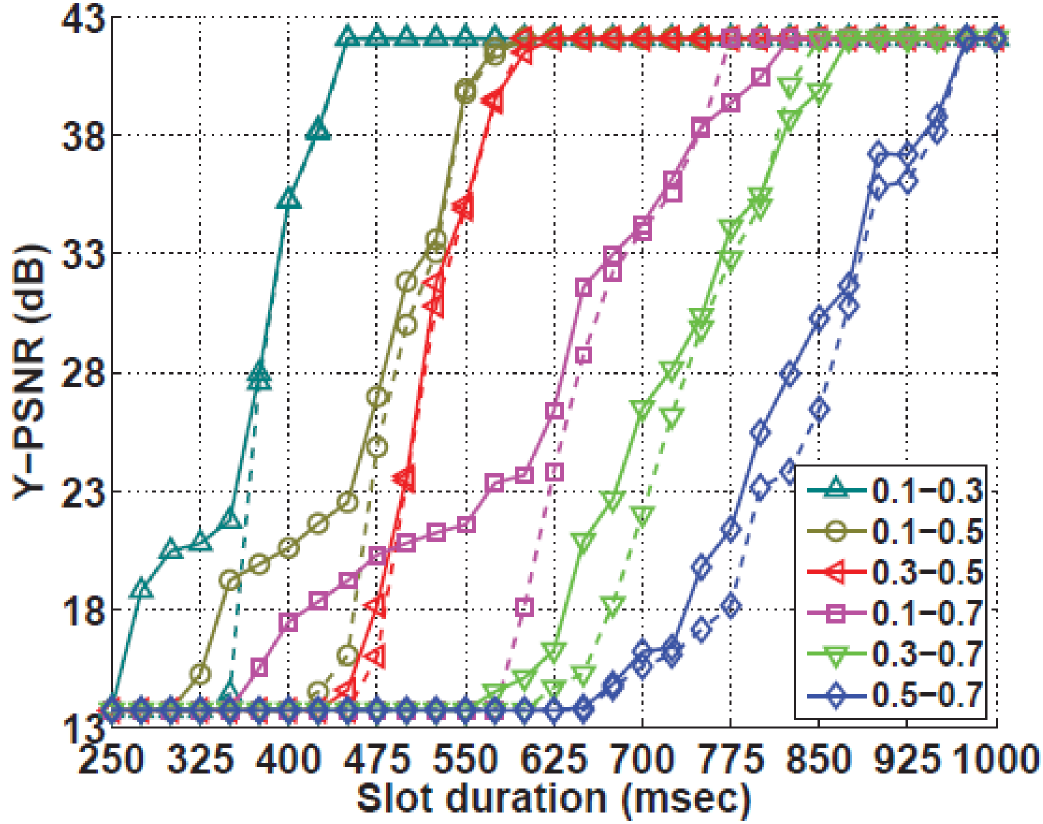




(c) The ViMOR's credit assignment compared to the $50-50\%$ equally distributed credit assignment for $k = 64$ and multiple e_1 and e_2 values. The marker of its line indicates the e_1 - e_2 or e_2 - e_1 values (same results). The solid lines correspond to the ViMOR's assignment and the dashed lines to the $50-50\%$ one.

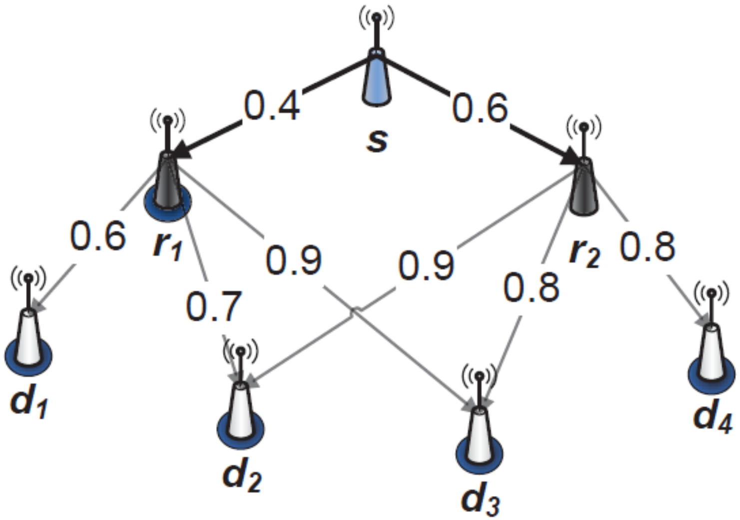
Experimenting in PLC





(d) PLC compared to RLC for $k = 64$, $\alpha = 1/3$ and multiple e_1 and e_2 values. The marker of its line indicates the e_1 - e_2. The solid lines correspond to PLC and the dashed lines to RLC.

Experimenting in broader topology



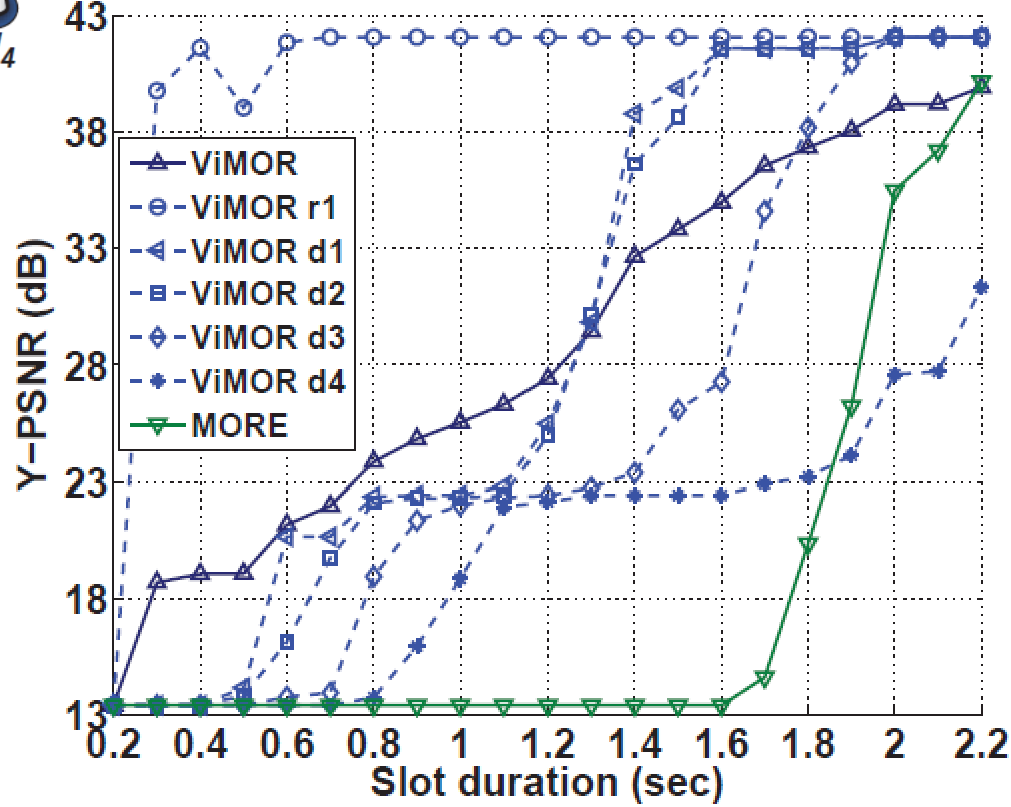


Fig. 4. Video performance comparison between ViMOR and MORE in the 7-nodes topology of Figure 2(b). The dashed lines correspond to the PSNR evaluation of the receipt video of each individual destination under ViMOR.

Thank you

Questions?

Why two-hop mesh networks?

- Source is able to know the link qualities of the whole mesh network, in order to estimate the x and y values

- MORE supports broader topologies, however, the number of transmissions of source and relays is estimated offline
  - Studies have shown that link metrics are sensitive and should be frequently updated (*Studying wireless routing link metric dynamics*, ACM IMC 2007)