Towards Truly Scalable MANETs Using MPR and Multi-radio Nodes

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Outline

- Summary of results on the order capacity of ad hoc networks
- Implications on the design of routing protocols for MANETs

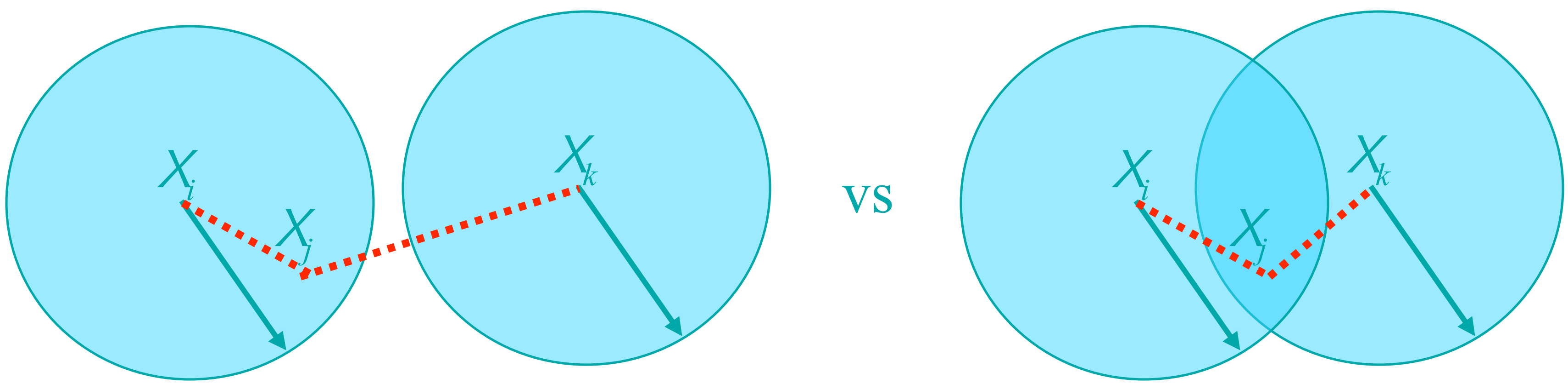
The Protocol Model

[1] Piyush Gupta and P. R. Kumar, "The Capacity of Wireless Networks, IEEE Trans. on Information Theory, vol. IT-46, no. 2, pp. 388-404, March 2000.

- Nodes (n) are uniformly distributed in the plane.
- X_j denotes the location of node j.
- A receiver can decode at most <u>*one*</u> transmission at a time.
- Transmission range is a circle with the same dimensions for all transmitters (*r(n)*), nodes are static and network is connected.
- A transmission is successful if

$$\left|X_i - X_j\right| \le r(n)$$

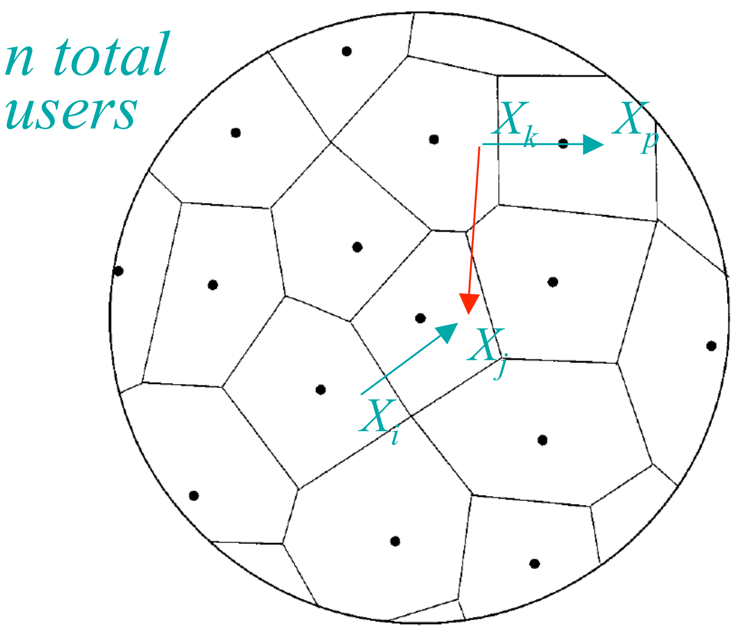
$$\left|X_k - X_j\right| \ge (1+\Delta)\ \mathrm{r(n)} \quad \text{for} \quad \Delta > 0$$



The Bad News…

[1] Piyush Gupta and P. R. Kumar, "The Capacity of Wireless Networks," IEEE Trans. on Information Theory, vol. IT-46, no. 2, pp. 388-404, March 2000.

- Multiple access interference (MAI) kills wireless ad hoc networks!
- As the number of nodes (n) increases, the throughput per node ($\lambda(n)$) decreases and average delay ($D(n)$) increases.



$$\lambda(n) = \Theta\left(\frac{1}{\sqrt{n\log(n)}}\right) \xrightarrow{n\to\infty} 0$$

$$D(n) = \Theta\left(\sqrt{\frac{n}{\log(n)}}\right) \xrightarrow{n\to\infty} \infty$$

Oh No! Now What?

- Alternative 1: Make one-hop relays walk to the destinations
  - **[2] M. Grossglauser and D. Tse, "Mobility Increases The Capacity of Wireless Ad Hoc Networks," Proc. IEEE Infocom 2001.**
- Alternative 2: See what can be done in static or mobile networks when packets must traverse multiple hops.
  - The more realistic case for MANETs…

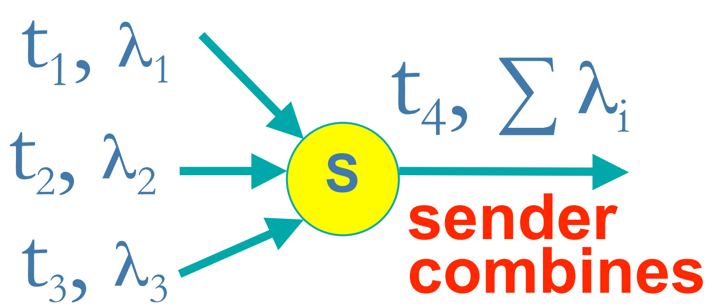
What Are The Alternatives?

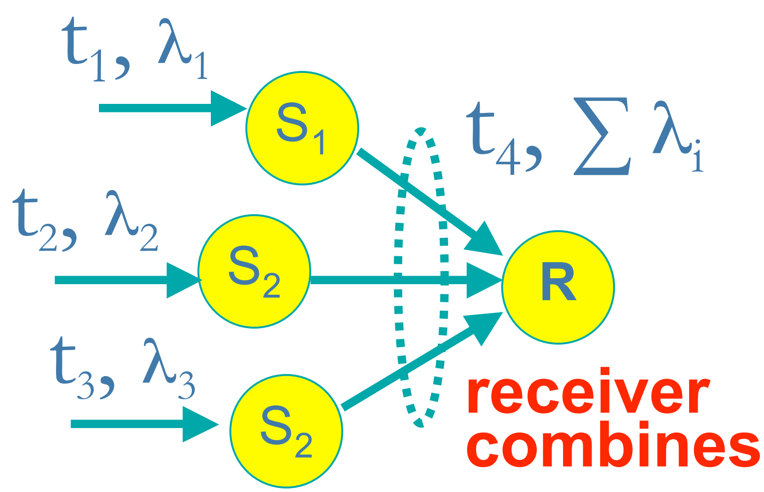
- The only way to make a wireless network scale is to address MAI around a receiver.
- We can only hope for an improvement of

$$\Theta(\log(n))$$

- Only two approaches are possible:

Sender-Oriented or **Receiver-Oriented**

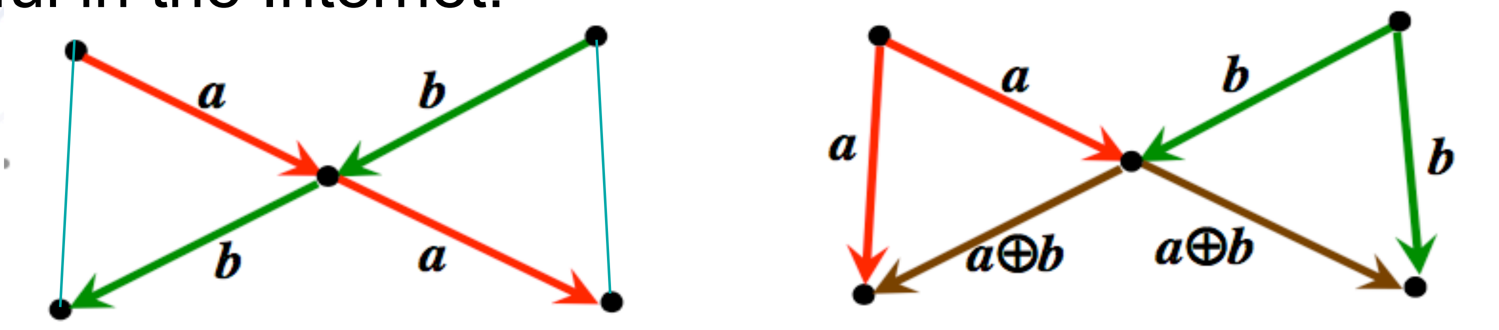




Network Coding (NC)

[3] R. Ahlswede, N. Cai, S.-Y. R. Li, and R. W. Yeung, "Network Information Flow", *IEEE Trans. on Information Theory*, IT-46, pp. 1204-1216, 2000.

- Attractive because it increases the attainable throughput for multicasting in wired nets.
- Useful in the Internet!



4 transmissions w/o NC, 3 with NC

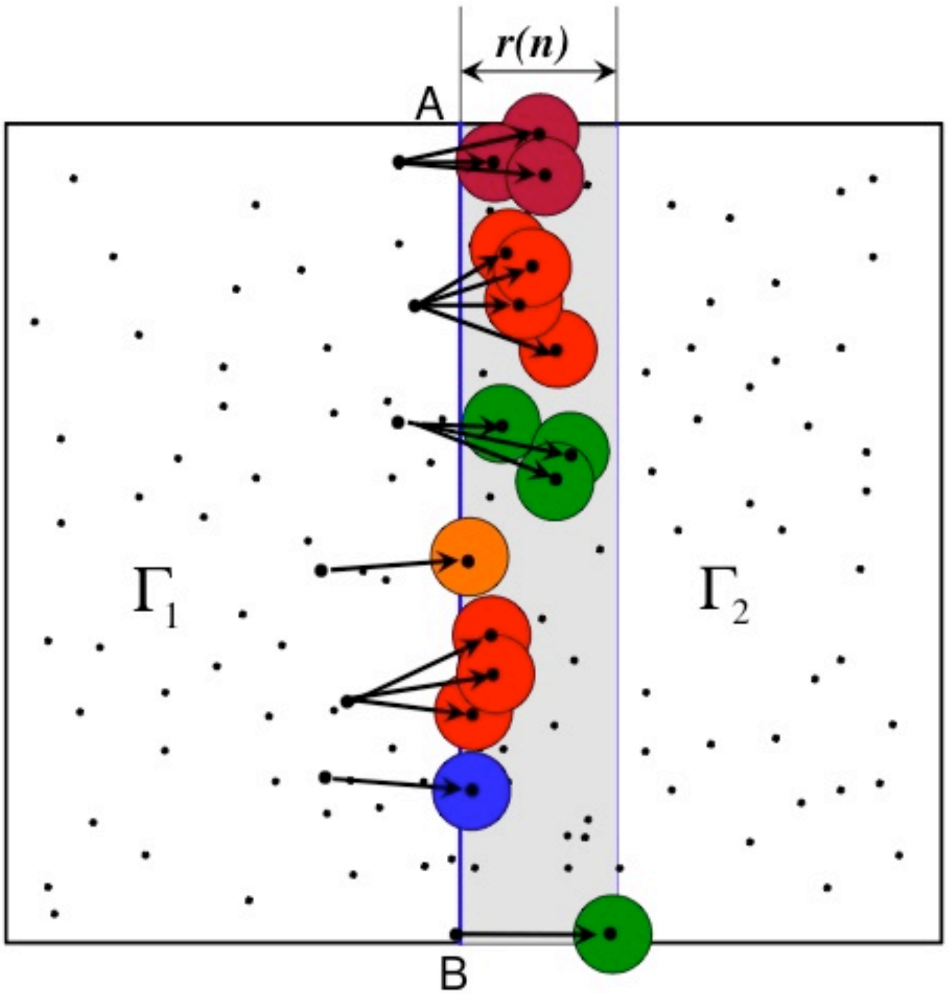
http://www.ifp.uiuc.edu/~koetter/NWC/index.html

DARPA ITMANET (NC as the scaling solution for MANETs?)

- Yes, but can it be used to *really increase* the capacity of wireless ad hoc nets?

Is NC The Answer?

[4] Running Liu, Dennis Goeckel and Don Towsley "The Throughput Order of Ad Hoc Networks Employing Network Coding and Broadcasting" IEEE MILCOM '06, October 23-25, 2006.

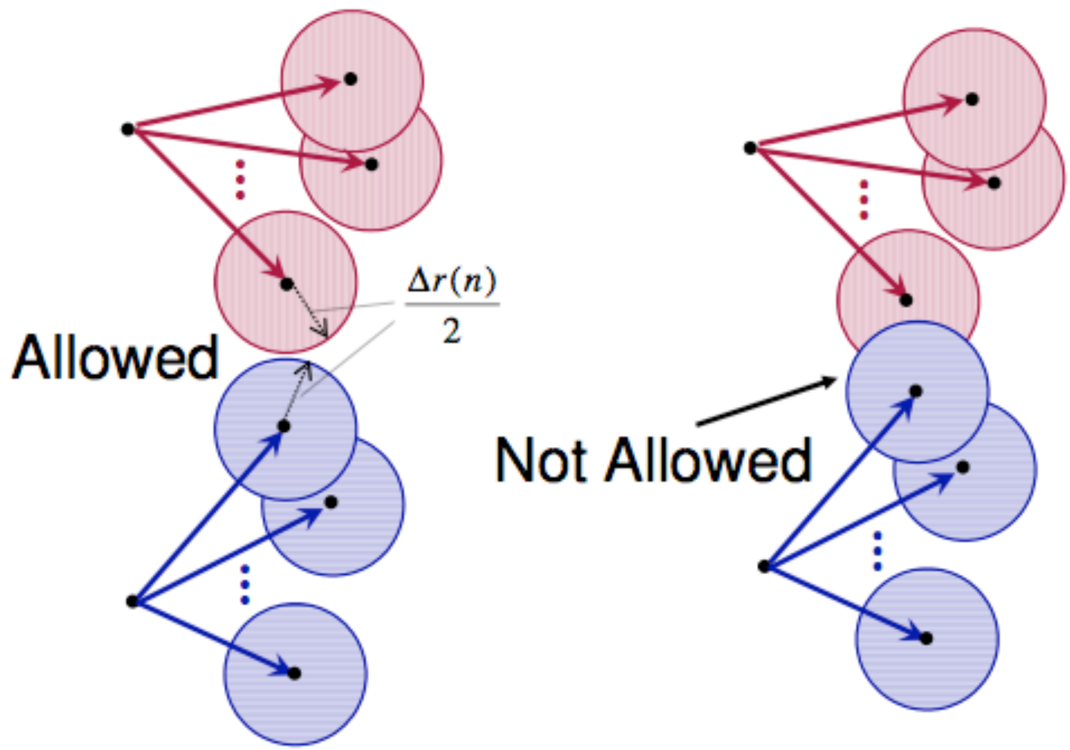


- Use the protocol model [1].
- Sparsity cut:
  - Cut induced by line with min. length that separates plane in two regions of equal area.
- With NC and broadcasting, one transmission reaches multiple receivers and packs multiple messages.
- **Does this do it?**

Is NC The Answer?

[4] Running Liu, Dennis Goeckel and Don Towsley "The Throughput Order of Ad Hoc Networks Employing Network Coding and Broadcasting" IEEE MILCOM '06, October 23-25, 2006.

- In a word, **NOPE!**
- **Key:**
  Unions of receiver disk must be *sender disjoin*
- This limits the senders that can transmit
- **Result:** NC produces *the same* order capacit for multiple unicast flov in a connected wireless network!



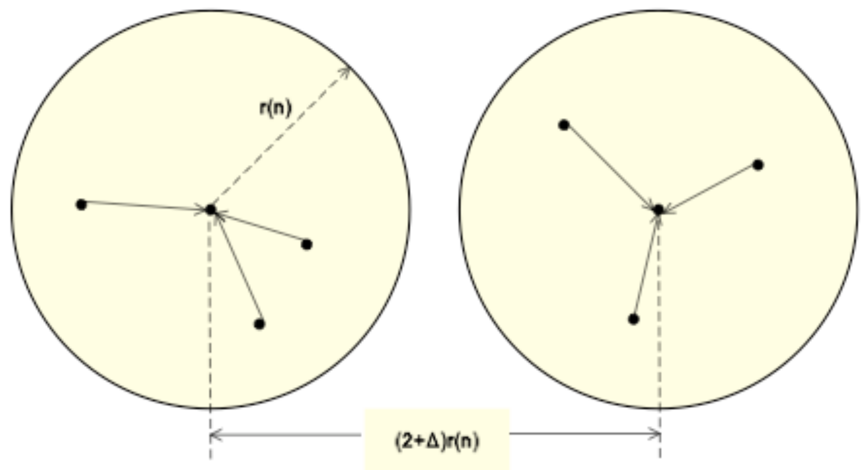
Is There An Alternative?

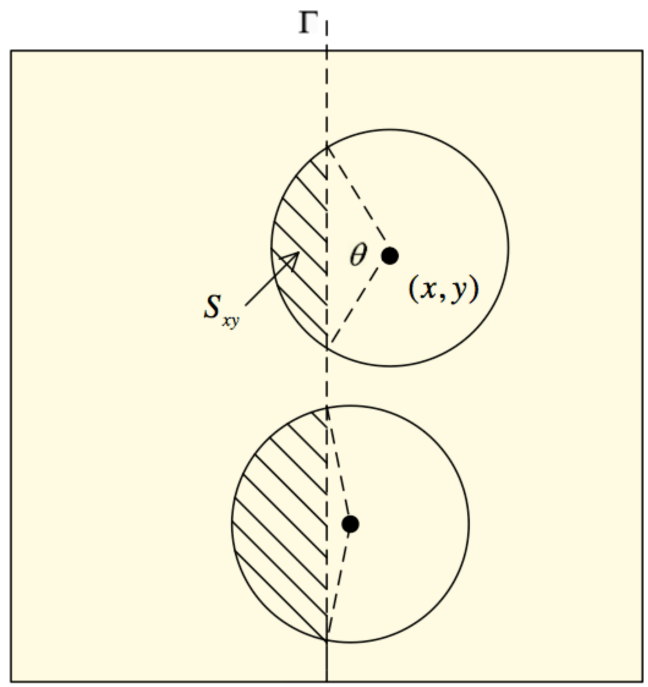
[5] JJ. Garcia-Luna-Aceves, H.R. Sadjadpour and Z. Wang, "Challenges: Towards Truly Scalable Ad Hoc Networks," Proc. ACM Mobicom 2007.

Yes!

Multi-Packet Reception:

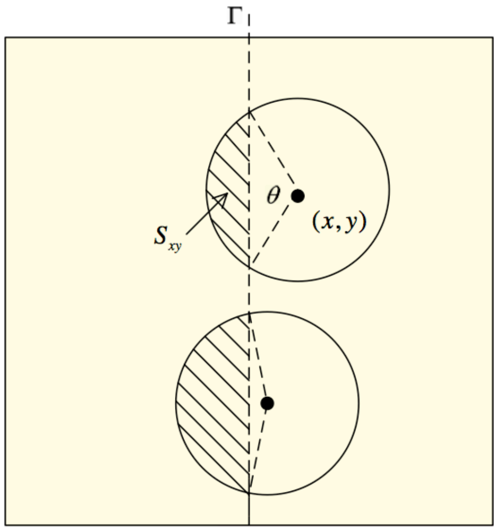
MIMO, multiple radios, etc.



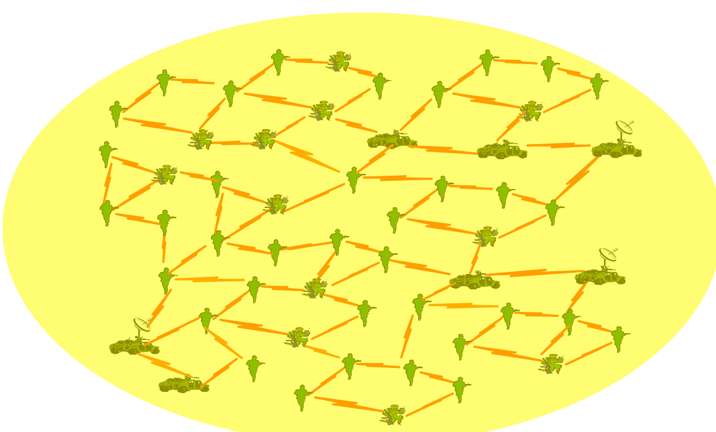


- Apply the protocol model [1] and the same "sparsity cut" from [4].
- With MPR, all nodes in shaded areas can transmit concurrently.
- Order of improvement is $\Theta(\log(n))$

Main Result: [Mobicom 2007]
MPR Can Render Truly Scalable Ad Hoc Networks!



- The negative impact of MAI within a receiving range is eliminated with MPR
- Remaining interference is ~0
- The order capacity is $\Theta\left(r(n)\right)$
- The order capacity increases as we increase r(n) !!!

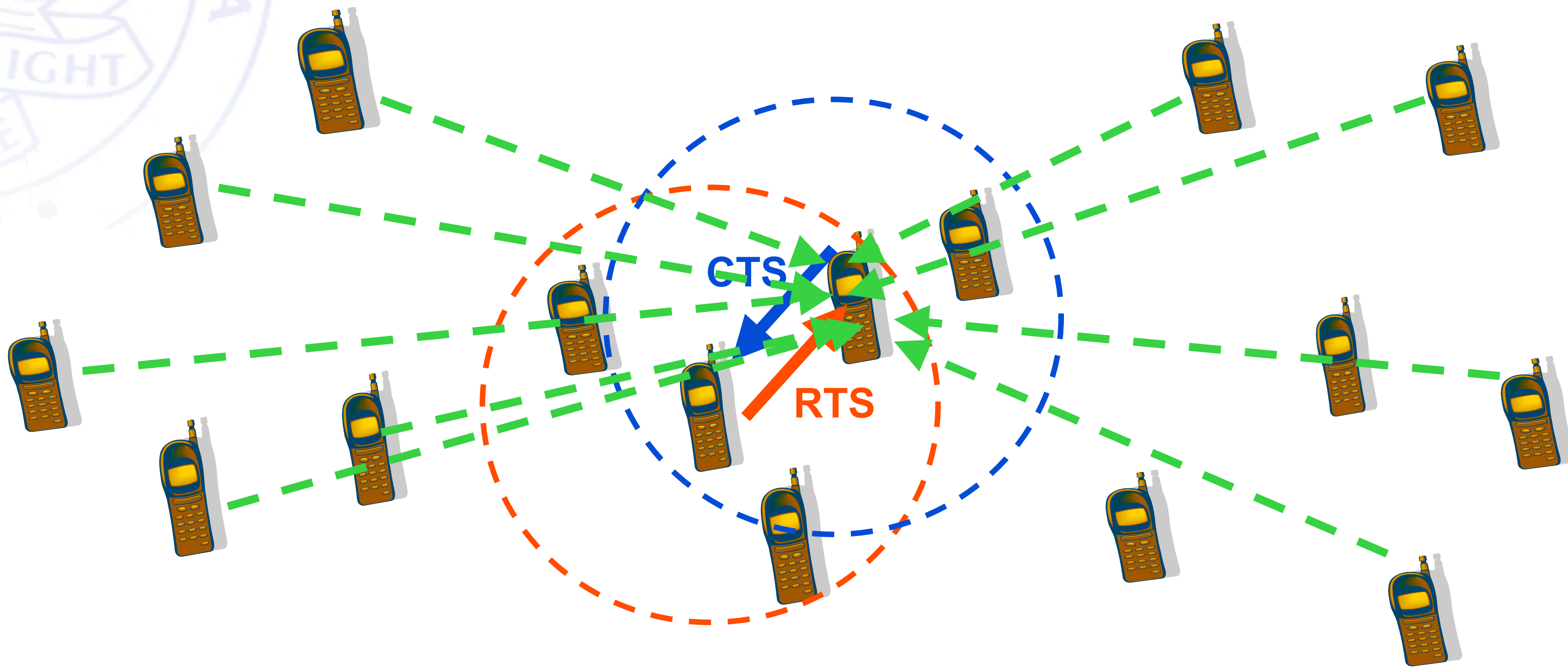


but…

- Network should be connected (min r(n))
- Transmission energy, complexity of transmitter and receiver (max r(n))

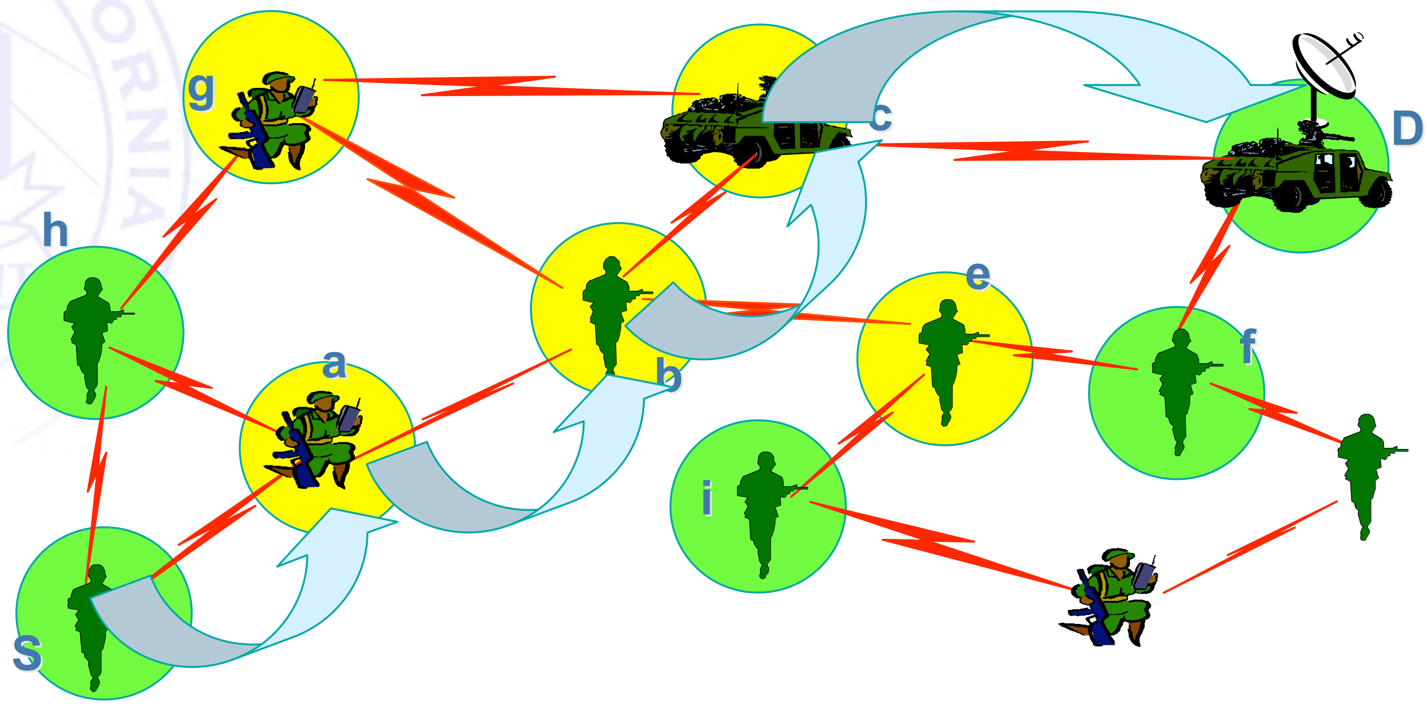
Why Should We Care?

We have been trying to schedule transmissions assuming a “two-hop” neighborhood



However, interference goes beyond a single hop!

Why Are Multi-Radio Nodes Important?



Nodes can transmit and listen in control channels and data channels concurrently

Smaller end-to-end delays

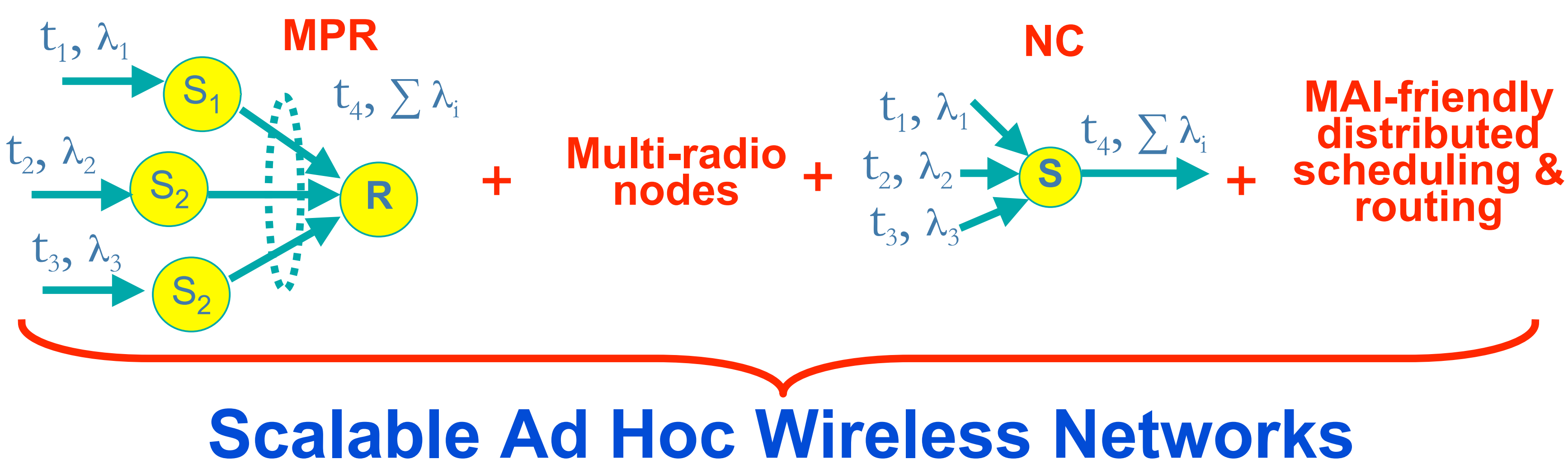
Implications

- MIMO, multi-channel, multi-radio nodes are (almost) here!
- Interference decays with distance
- MPR is simpler than NC and is localized
- MPR *requires* orchestration of senders and receivers, and such orchestration must be distributed
- We need to exploit concurrency at the MAC level and redundancy at the network level.

Implications

Replace

- Avoiding MAI with embracing MAI (from one-to-one to many-to-many).
- Single paths with multipaths
- Single copy forwarding with multi-copy forwarding
- Multicast trees with multicast concurrency meshes
- Multi-point relays (minimize number of broadcast transmissions) with feasible concurrency relays (optimize number of concurrent broadcast transmissions)



Thanks!