UNIVERSITÄT OSNABRÜCK

Bricks for future Mobile Networking

Brick 2: Routing and Capacity in Wireless Multi-hop Networks

Mobile Communication, WS 2014/2015, Kap.5

Prof. Dr. Nils Aschenbruck

Wireless Multi-Hop Network – Core Challenges

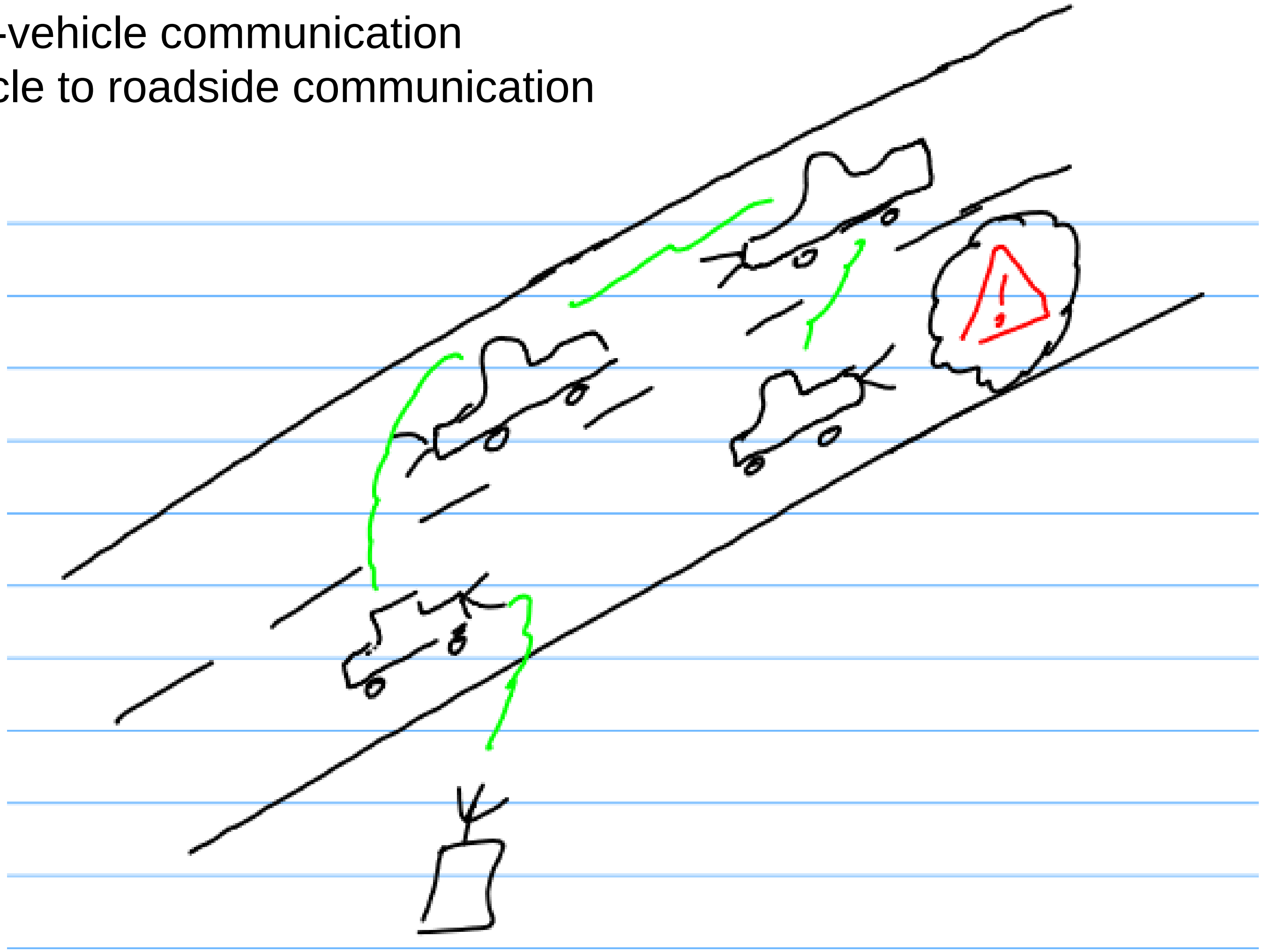
- **Wireless Multi-Hop Network**
  - dynamic topologies
  - battery-driven nodes
  - wireless communication
  - self-configuration
  - limited security

- **Tactical Wireless Multi-Hop Network**
  - hierarchically structured
  - heterogeneous nodes
  - coordinated movement
  - high security level needed

- **Core Challenges**
  - Routing
  - Robustness
  - Sensor Management
  - Communication Management
  - Security

Scenario – A Day on the Beach

- inter-vehicle communication
- vehicle to roadside communication




Hurricane Charley
Eyewall Video
Charlotte Harbor, FL
Aug.13th 2004

Ad-hoc Routing – Historical Notes

1972	Packet Radio Network
early **1980s**	Survivable Adaptive Radio Networks
1994	*Destination Sequenced Distance-Vector* (**DSDV**) Charlie Perkins, Pravin Bhagwat
1996	*Dynamic Source Routing* (**DSR**) – term DSR introduced in Dave Johnson, David Maltz
1999	*Ad-hoc On-demand Distance-Vector* (**AODV**) Charlie Perkins, Elizabeth Royer
2003	**AODV** RFC 3561 **OLSR** RFC 3626
2004	TBRPF RFC 3684
2007	**DSR** RFC 4728

Ad-hoc Routing – Current Status

Manet Status Pages - rekonq

Manet Status Pages

https://tools.ietf.org/wg/manet/

IETF TOOLS

IETF Home
About Tools
Tools:
diffs spell
xml2rfc idnits
tracker src
News
Get Passwd
IETF-92:
Rooms
Agenda
Calendar
Documents
RFCs
Doc fetch:
Wikis:
IESG IRTF
Dev RSOC
Chairs Edu
Tools BOFs
NomCom
Areas
WGs:
concluded...
6lo
6man
6tisch
Abfab
Ace
Alto
Ancp
Anima
Appsawg
Aqm
Avtcore
Avtext
Bess
Bfcpbis
Bfd
Bmwg
Calext
Ccamp
Cdni
Clue
Codec
Conex

Manet Status Pages

Mobile Ad-hoc Networks (Active WG)

Rtg Area: Alia Atlas, Adrian Farrel | 1997-Jun-12 —
Chairs:
Justin Dean
Stan Ratliff

Drafts | **Agendas** | **Minutes** | **Wiki** | **Training** | **Issues** | **Svn** | **Charters** | **Jabber Room,Logs** | **List Archive** | **List search:**

Working Group Documents:

Document collections: epub mobi

Draft name	Rev.	Dated	Status	Comments, Issues
Active:				
draft-ietf-manet-aodvv2	-06	2014-12-30	Active	24/39
draft-ietf-manet-dlep	-07	2014-10-24	Active	1/1
draft-ietf-manet-olsrv2-dat-metric	-04	2014-12-12	Active	
draft-ietf-manet-olsrv2-management-snapshot	-03	2014-09-15	Active	
draft-ietf-manet-olsrv2-multipath	-02	2014-10-27	Active	
draft-ietf-manet-report-mib	-04	2014-12-08	Active	
draft-ietf-manet-rfc6779bis	-01	2014-11-11	Active	
draft-ietf-manet-smf-sec-threats	-01	2014-09-15	Active	
draft-ietf-manet-tlv-naming	-00	2015-01-05	Active	
IESG Processing:				
draft-ietf-manet-ibs	-03	2014-09-04	IESG Evaluation::AD Followup	
draft-ietf-manet-nhdp-optimization	-03	2014-09-05	Approved-announcement to be sent::Revised I-D Needed	2/2
draft-ietf-manet-olsrv2-multitopology	-04	2014-07-21	AD Evaluation::Point Raised - writeup needed	3/3

Published:

Draft name	Rev.	Dated	Status	Obsoleted by/*(Updated by)*
draft-ietf-manet-aodv	-13	2003-02-27	RFC 3561	
draft-ietf-manet-dsr	-10	2004-07-21	RFC 4728	
draft-ietf-manet-iana	-07	2007-11-18	RFC 5498	
draft-ietf-manet-issues	-02	1998-10-19	RFC 2501	
draft-ietf-manet-jitter	-04	2007-12-04	RFC 5148	
draft-ietf-manet-nhdp	-15	2010-12-19	RFC 6130	*(RFC 7183 RFC 7188)*
draft-ietf-manet-nhdp-mib	-19	2012-09-09	RFC 6779	
draft-ietf-manet-nhdp-olsrv2-sec	-05	2013-09-11	RFC 7183	
draft-ietf-manet-nhdp-olsrv2-tlv-extension	-05	2014-03-05	RFC 7188	
draft-ietf-manet-nhdp-sec-threats	-06	2013-06-17	RFC 7186	
draft-ietf-manet-olsr	-11	2003-07-03	RFC 3626	
draft-ietf-manet-olsrv2	-19	2013-03-24	RFC 7181	*(RFC 7183 RFC 7187 RFC 7188)*
draft-ietf-manet-olsrv2-metrics-rationale	-04	2013-05-01	RFC 7185	
draft-ietf-manet-olsrv2-mib	-12	2013-06-25	RFC 7184	
draft-ietf-manet-olsrv2-rmpr-optimization	-01	2014-02-24	RFC 7187	
draft-ietf-manet-packetbb	-17	2008-11-18	RFC 5444	
draft-ietf-manet-packetbb-sec	-09	2012-03-06	~~RFC 6622~~	RFC 7182
draft-ietf-manet-rfc6622-bis	-06	2013-11-16	RFC 7182	

The most basic routing strategy is flooding:

- every router broadcasts every packet not intended for him once

Advantage:

- packet is **guaranteed to be delivered** (if a path exists) (given sufficient capacity)
- packet will take the shortest route
- very few state information required (to detect duplicates)

Disadvantage:

- Huge overhead due to **massive duplication** of packets!!!

Flooding is the most important operation in ad hoc networks

But it is very costly in wireless environments (detailed reason later)

- do it seldom
- do it efficiently

Flooding: A Broadcast Storm

Every incoming packet is sent out on every outgoing line.

However, in wireless networks there is **no line!**

- every transmission blocks not only the sender and receiver, but any neighbouring station in detection range!
- since every neighbour re-broadcasts the packet, a single packet flooding may **block a certain area** for a very long period!
- simultaneous broadcasts may cause **collisions**
- broadcasts are (usually) unacknowledged -> **packet loss**

This phenomenon is called **broadcast storm**

Further details:
TSENG, Yu-Chee et al.: The Broadcast Storm Problem in a Mobile Ad Hoc Network. In: Wireless Networks 8 (2002), Nr. 2-3, S. 153-167.

	Reaktiv	Proaktiv	Hybrid
Unicast	AODV, DSR, Dymo, TORA	OLSR, TBRPF, DSDV	ZRP, HWMP
Multicast	ODMRP, MAODV	MOLSR	…
Geocast			
Broadcast			

Reactive Routing (a.k.a on-demand routing)

Challenge: Many routing entries are never needed

- much more routing updates due to mobility
- not every station is communicating with every other station

- **Solution:** Maintain routing information **for active connections** only
  - discover routes **on-demand** (i.e. reactively)
  - disadvantage: increased route-setup time

Challenge: How to get the initial routing information?

Solution: flood the network to search for a route

- if a path exists, it is likely to be discovered

Challenge: What happens when a route fails?

Solution: repeat the route search procedure

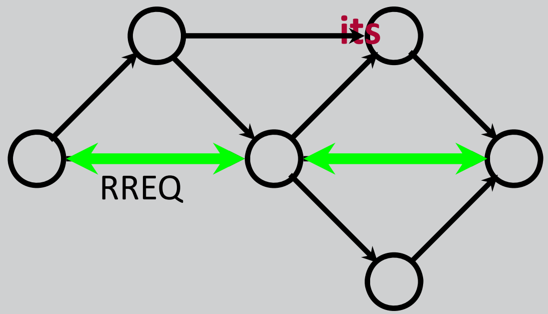
Note: Each route discovery causes a **broadcast storm.**

Reactive Route Discovery

One of the best known reactive routing protocols is AODV (Ad-hoc On-Demand Distance-Vector)

Reactive Route Discovery (principle)

1. The source node floods a **route request** (RREQ) through the network.
   - each RREQ carries a RREQ-ID which identifies it uniquely (in conjunction with the source address)
2. Upon reception of a RREQ, a node **updates its routing entry** towards
   1. the preceding node and
   2. the source node (reverse path).
3. The receiving node checks whether it is the destination
   1. If not: re-broadcast the RREQ
   2. If yes: Generate a **route reply** and send it to the source (unicast). Each receiving node can update its routing entry towards the destination.
4. If the RREQ is a **duplicate**, it is silently **discarded**.



AODV discovers the **fastest route**

- most likely a short one
- likely to be little congested

Using other metrics is not trivial!

AODV has **no periodic updates**

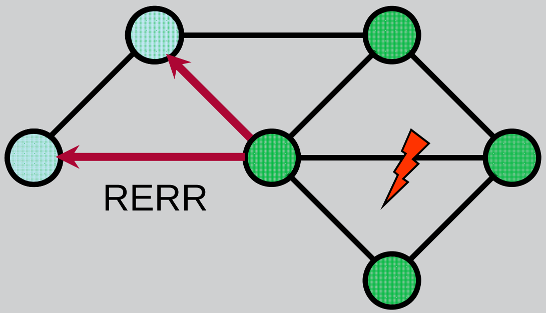
- once discovered, a route is used until it breaks

What happens when a link breaks?

- recall that AODV does not maintain routes proactively

Route Maintenance procedure

1. Invalidate routing table entry
2. Identify every affected upstream neighbour
3. Send **route error** message (RERR)
4. Initiate new route discovery
   (with increased sequence number)



Interruption may be considerable

- detection of link break
  - may involve several retransmission attempts
- RERR signalling
  - unicast transmission
- RREQ/RREP signalling

Optimisations for AODV

Reduce downtime:

Local Repair

- Start discovery from point of failure
- disadvantage: route may degrade gradually
  - solution: inform source about new route

Save bandwidth:

Expanding Ring Search

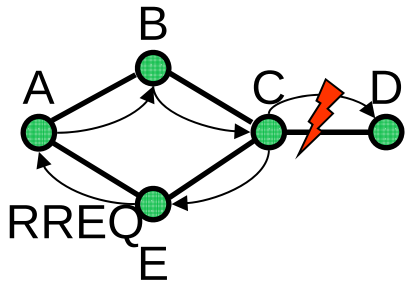
- Limit the scope of a RREQ by setting a small TTL in the IP header and increase the search radius gradually
- Use offset for following discoveries
- **Note**: this saves bandwidth for near destinations only

Save Route-Setup Time:

Early Reply

- if a router on the way knows a route to the destination, it may send an early reply to the source
  - limits the broadcast storm

Suppose the following scenario in which A sends to D via route ABCD:



1. Link CD breaks
2. RERR from C to A gets lost
3. Later C discovers D
4. A receives this RREQ via C-E-A and replies (because it „knows“ a route via B)

☛ **Loop!**

Solution: **Sequence numbers**

- each node maintains its own (destination) sequence number
- is increased for every route discovery
- intermediate stations may reply only if they know a more recent route than requested in the RREQ

Dynamic Source Routing (DSR)

Idea: Source Routing is trivially loop-free (collect router addresses in RREQ)

AODV	DSR
Source knows distance and nexthop	Source determines complete route
Caching of distance-vector information in intermediate routers	No state information in intermediate routers
Storage overhead in every router	Overhead in every packet
prefers shortest delay (reply once)	prefers shortest path (multiple RREPs)

- Optimisations:
  - **Route Cache** (promiscuous mode)
    - advantage: fewer discoveries due to partial topology information
    - disadvantage: outdated information causes use of invalid routes (waste of time and ressources) and pollutes other station‘s route caches
    - when to purge stale entries
  - **Flowlabel** (where‘s the difference to AODV?)

Disadvantage of reactive protocols: long route setup time!

Proactively, this can be avoided (because routing information is constantly updated and thus, instantly available).

Problem: Huge overhead for periodic flooding of topology information.

Three solutions were discussed in the MANET community:

Fisheye State Routing

Link state updates are sent infrequently for distant destinations

- information for distant destination is “blurred”.
- routing information gets more precise as packets approach the destination

Topology Broadcast Based on Reverse-Path Forwarding

Link state updates contain source trees instead of complete topology information

- from all source trees, a station may reconstruct a concise view of the topology

Optimized Link-State Routing

Only a subset of all nodes forwards link state updates.

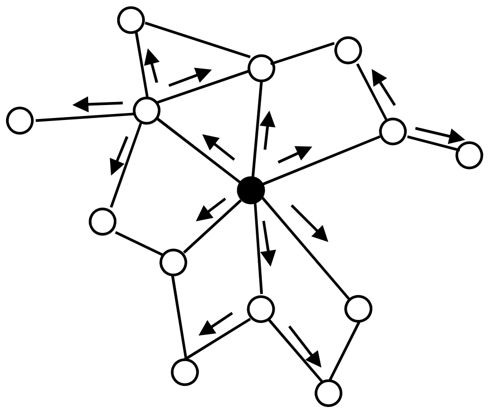
- information for all destinations is available in the network
- routing only via the “knowing” subset

OLSR has been sort of the winning solution and is frequently used (e.g. by Freifunk.net).

Optimized Link State Routing (OLSR)

- provides an efficient flooding scheme
- otherwise similar to Internet link state protocols

Multi-Point Relay



- optimal:
  - connected dominating set
  - NP complete

Greedy algorithm

repeat

sort neighbours by number of covered 2-hop-neighbours

select neighbour with largest coverage

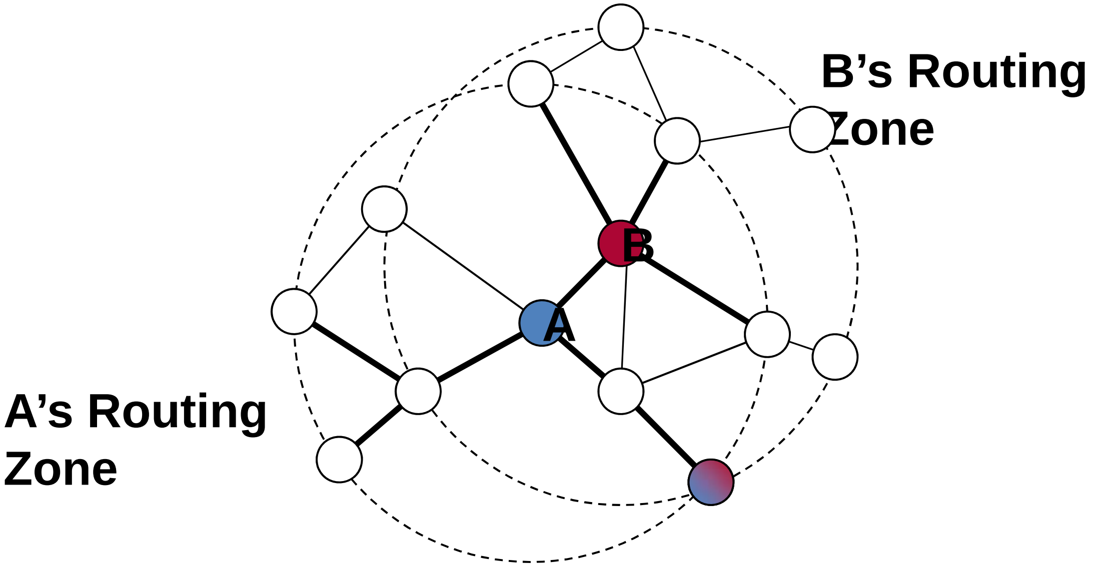
delete covered nodes from 2-hop-neighbourhood

until all nodes are covered

A Hybrid Approach

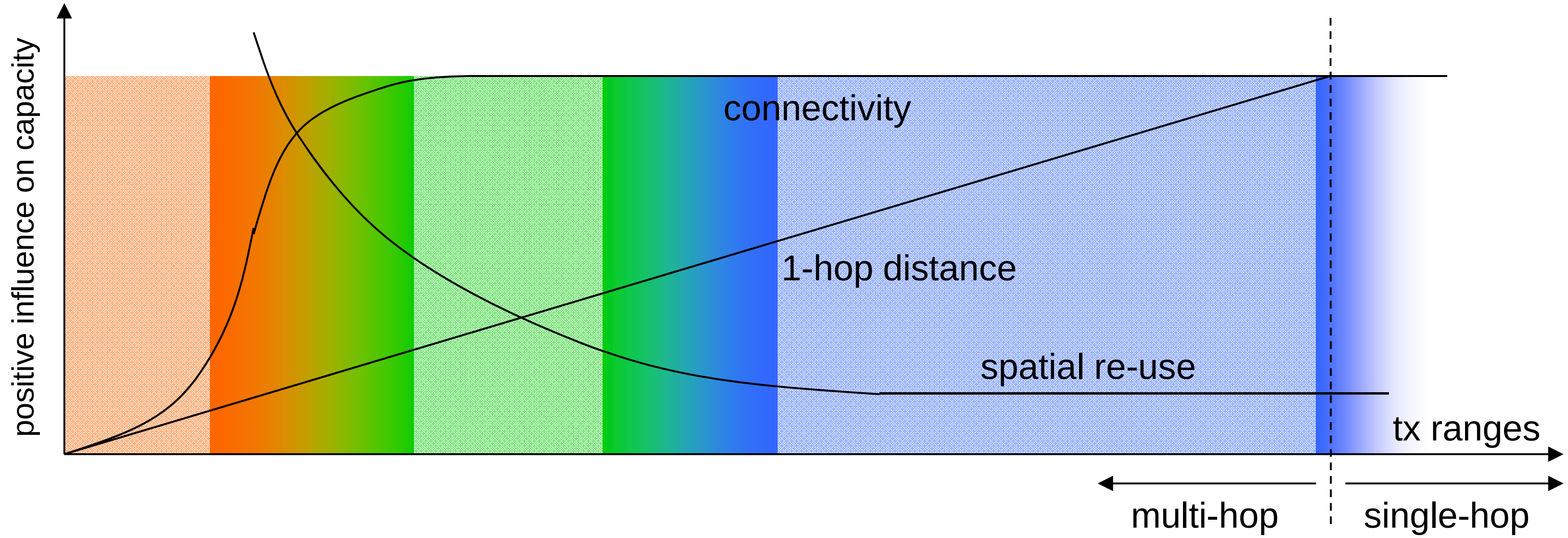
- **Idea:** Combine benefits of proactive and reactive routing

Zone Routing



- Maintain a routing zone of *n* hops **proactively**
- Discover routes to far destinations **reactively**
- Use **bordercasting** instead of flooding

Capacity of Wireless Networks



Literature

Gupta, P.; Kumar, P.R.:
"The Capacity of Wireless Networks",
IEEE Transactions on Information Theory, Vol.:46, Issue: 2, Mar. 2000
http://dx.doi.org/10.1109/18.825799

The Capacity of Wireless Networks

Piyush Gupta, *Student Member, IEEE*, and P. R. Kumar, *Fellow, IEEE*

***Abstract*—When n identical randomly located nodes, each capable of transmitting at W bits per second and using a fixed range, form a wireless network, the throughput $\lambda(n)$ obtainable by each node for a randomly chosen destination is $\Theta\left(\frac{W}{\sqrt{n \log n}}\right)$ bits per second under a noninterference protocol.**

If the nodes are optimally placed in a disk of unit area, traffic patterns are optimally assigned, and each transmission's range is optimally chosen, the bit–distance product that can be transported by the network per second is $\Theta(W\sqrt{An})$ bit-meters per second. Thus even under optimal circumstances, the throughput is only $\Theta\left(\frac{W}{\sqrt{n}}\right)$ bits per second for each node for a destination nonvanishingly far away.

Similar results also hold under an alternate physical model where a required signal-to-interference ratio is specified for successful receptions.

Fundamentally, it is the need for every node all over the domain to share whatever portion of the channel it is utilizing with nodes in its local neighborhood that is the reason for the constriction in capacity.

Splitting the channel into several subchannels does not change any of the results.

Some implications may be worth considering by designers. Since the throughput furnished to each user diminishes to zero as the number of users is increased, perhaps networks connecting smaller numbers of users, or featuring connections mostly with nearby neighbors, may be more likely to be find acceptance.

example of such networks is multihop radio networks or *ad hoc* networks. Another possibly futuristic example, see [1], may be collections of "smart homes" where computers, microwave ovens, door locks, water sprinklers, and other "information appliances" are interconnected by a wireless network.

It is to these types of all wireless networks that this paper is addressed. Such networks consist of a group of nodes which communicate with each other over a wireless channel without any centralized control; see Fig. 1. Nodes may cooperate in routing each others' data packets. Lack of any centralized control and possible node mobility give rise to many issues at the network, medium access, and physical layers, which have no counterparts in the wired networks like Internet, or in cellular networks.

At the network layer, the main problem is that of routing, which is exacerbated by the time-varying network topology, power constraints, and the characteristics of the wireless channel; see Ramanathan and Steenstrup [2] for an overview. The choice of medium access scheme is also difficult in *ad hoc* networks due to the time-varying network topology and the lack of centralized control. Use of TDMA or dynamic assignment of frequency bands is complex since there is no centralized control as in cellular networks, FDMA is inefficient in dense networks,

Gupta/Kumar: Capacity of Wireless Networks

- each node can transmit at **W bits per second over a wireless channel**
- due to **spatial separation**, several nodes can make wireless transmissions simultaneously

- random scenario, **n nodes are randomly located**,
  - i.e., independently and uniformly distributed,
- each node has a **randomly chosen destination** to which it wishes to send **λ(n) bits per sec.**
- all transmissions employ the **same nominal range or power**

Main Result 4: For the Physical Model a throughput of $\lambda(n) = \frac{cW}{\sqrt{n \log n}}$ bits per second is feasible, while $\lambda(n) = \frac{c'W}{\sqrt{n}}$ bits per second is not, for appropriate c, c', both with probability approaching one as $n \to \infty$.

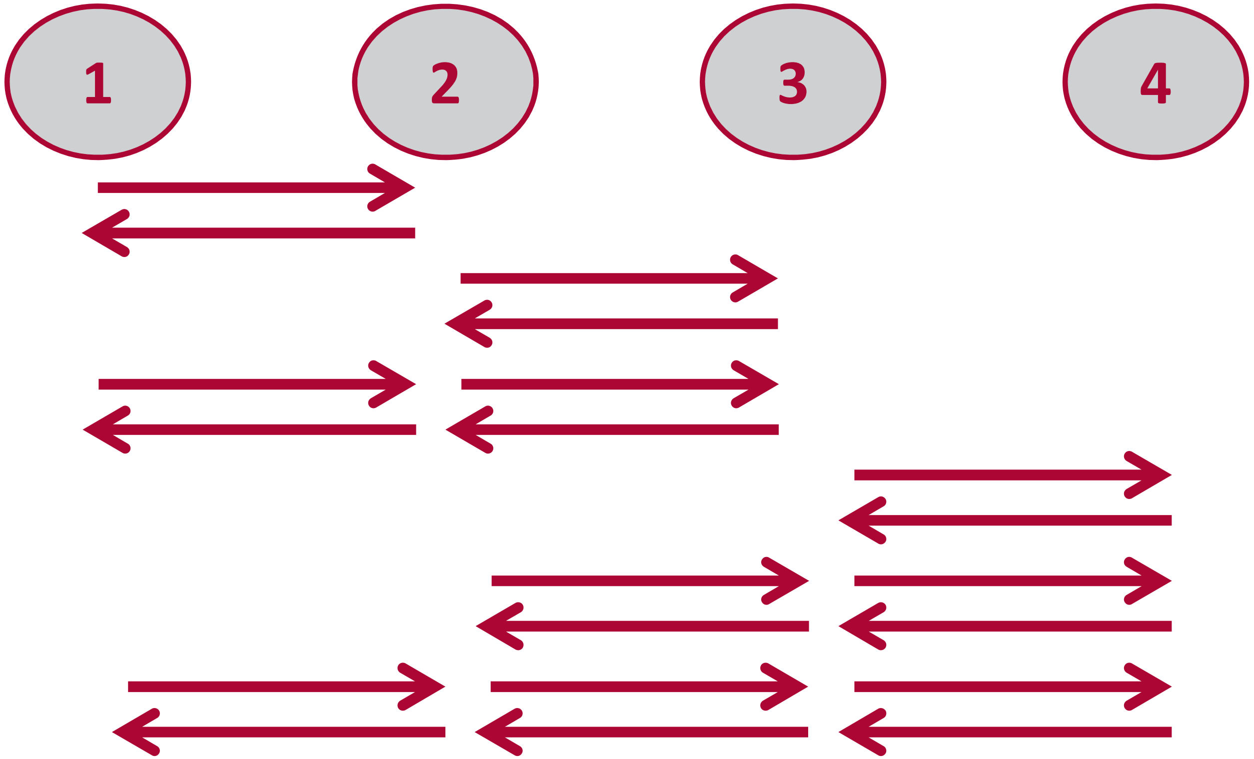
A **perfect scheduling algorithm** which
- knows the locations of all nodes;
- knows all traffic demands;
- coordinates wireless transmissions temporally and spatially;
- assumes the nodes are not mobile.

If this is not true, then the **capacity can only be even smaller**.

Gupta/Kumar: Capacity of Wireless Networks – Implications

- “Perhaps efforts should be targeted at designing **networks with small numbers of nodes**.”
- “.. one can group the nodes into small clusters or “cells,” where in each cell one can designate one specific node to carry all the burden of relaying multihop packets, if so desired. Thus a division of labor is possible, were this to be found profitable.”
- “dividing the channel into subchannels does not change any of the results.”

… think of routing in a simple chain in one collision domain …



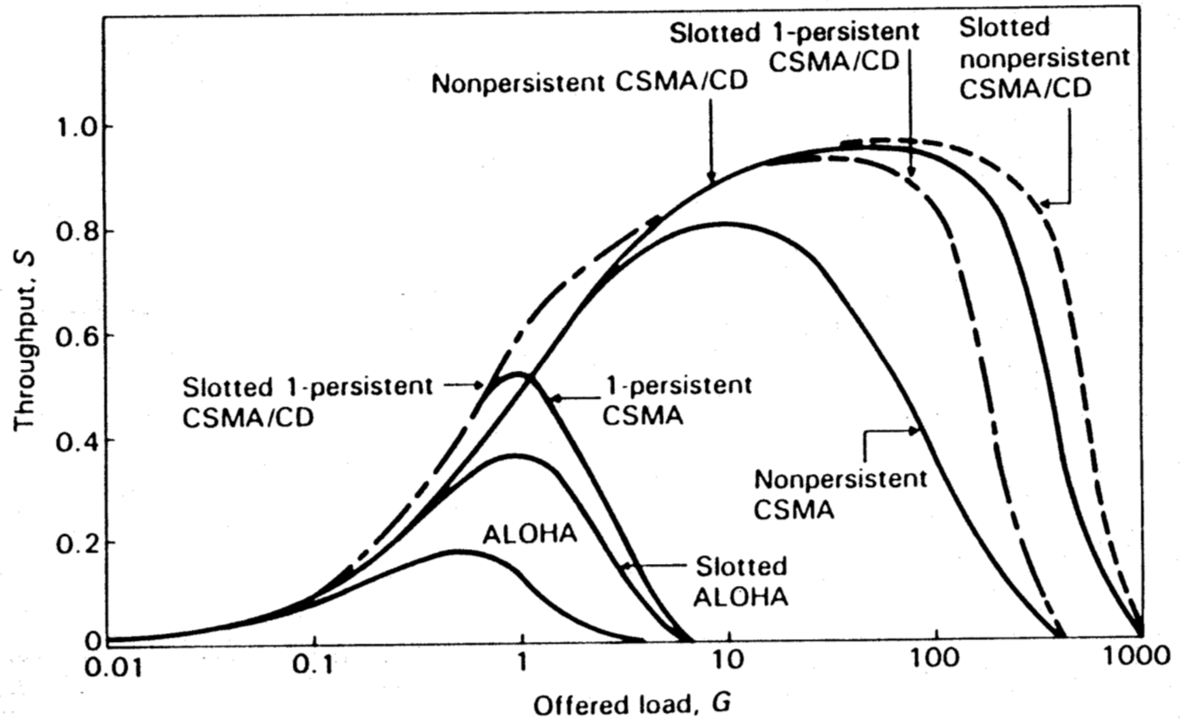
n = 2 => 2

n = 3 => 8

n = 4 => 20

…

.. and connect it to results we have seen before ... (cf. chap. 3c)



Source:
J.L. Hammond, P.J.P. O'Reilly,
“Performance Analysis of Local Computer Networks,” Addison-Wesley, 1986

The Incredibles

- 151 papers presented at MobiHoc (2000-2005)
- 114 of 151 (75.5%) are simulation-based papers
- 34 of 114 (29.8%) did not state simulator used
- 106 of 114 (93%) did not address initialization bias

MANET Simulation Studies: The Incredibles *

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Simulation is the research tool of choice for a majority of the mobile ad hoc network (MANET) community. However, while the use of simulation has increased, the credibility of the simulation results has decreased. To determine the state of MANET simulation studies, we surveyed the 2000-2005 proceedings of the ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc). From our survey, we found significant shortfalls. We present the results of our survey in this paper. We then summarize common

Experimental Evaluation of Wireless Simulation Assumptions

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0: The world is flat.
1: A radio's transmission area is circular.
2: All radios have equal range.
3: If I can hear you, you can hear me (symmetry).
4: If I can hear you at all, I can hear you perfectly.
5: Signal strength is a simple function of distance.

see also Kotz et al.: "Experimental Evaluation of Wireless Simulation Assumptions" in SIMULATION: Transactions of The Society for Modeling and Simulation International, 2007.

Classification

Terms used in literature:

- Ad-hoc networks
- MANETs
- Mesh Networks
- Sensor Networks
- Ubiquitous Computing
- Cooperating Objects
- Multi-hop networks
- Underwater Sensor Networks
- Opportunistic Network
- Delay Tolerant Network
- Vehicular Ad-hoc Networks (VANETs)

One classification:

Ad-hoc Networks:
- multi-hop
- no infrastructure
- mobile devices

Mesh Networks:
- multi-hop
- meshed backbone

Sensor Networks:
- multi-hop
- embedded sensors

Opportunistic Networks:
- multi-hop
- no infrastructure
- delay tolerant
- partitioned