Selected Research Projects in Networking

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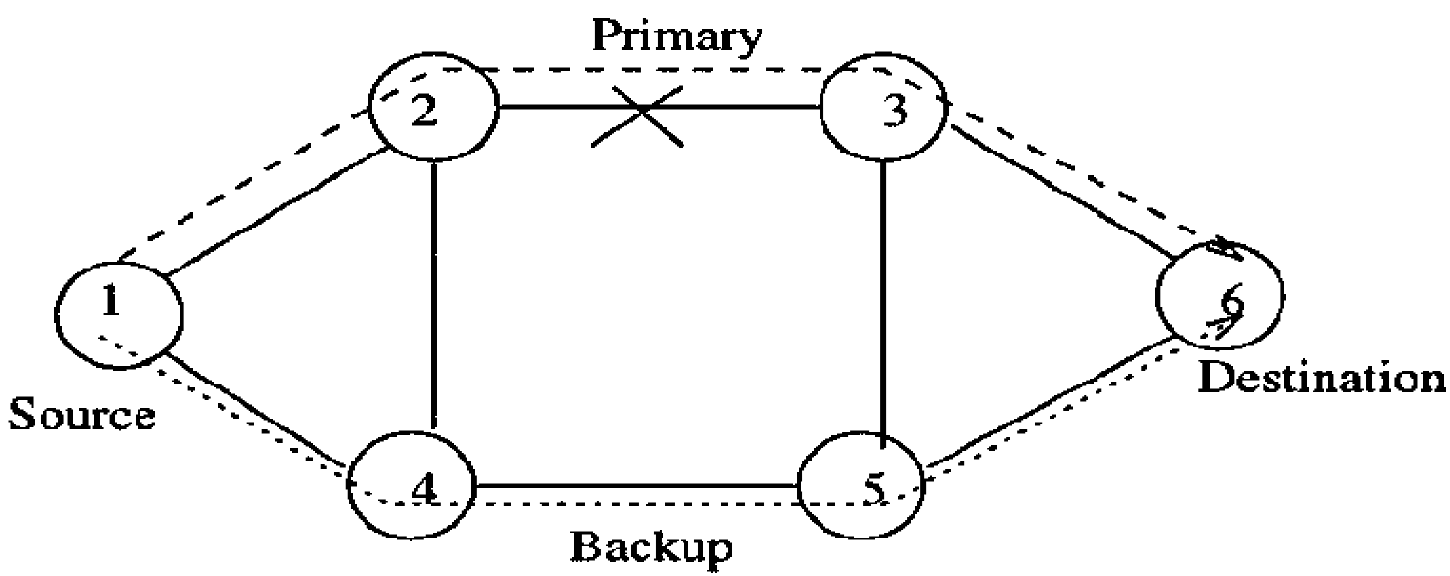
Overview of Research Areas

- Network Survivability
- Wireless Systems
- Internet (TCP/IP)
- Optical Networks

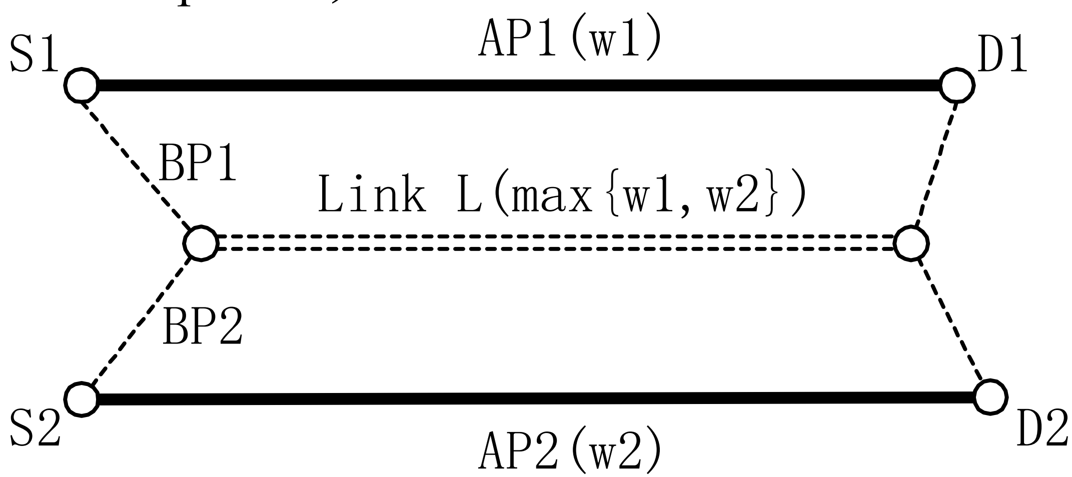
Survivability: Path Protection

- each connection uses an *active (*or *primary) path* (AP) and a (disjoint) *backup path* (BP).
- allocates *w* units of bandwidth on AP & BP.
- protects against any single link (or node) failure (except for the *src* or *dest* node).



Shared Path Protection: Principle

- *if and only if* two APs are disjoint, their BPs can share *backup bandwidth* (BBW) on a common link *L* (i.e., total BBW on *L* = max$\{w_1, w_2\}$ instead of $w_1 + w_2$).



Problem Statement

- Given: a network and dynamic (i.e., *online*) requests for establishment of connections
- Find: a disjoint AP and BP pair for each new request
- Optimization Objective: minimize the total bandwidth consumption (on the AP and BP)
- Constraint: cannot re-arrange existing connections

Challenges

- Using the APF heuristic (find a shortest AP first, and then a shortest (disjoint) BP) only achieves *sub-optimal* results
- So does using a shortest pair of (disjoint) paths (which can be found using a polynomial-time algorithm) due to potential bandwidth sharing among BPs
- Jointly optimize an AP/BP pair is in fact NP-hard
- Using *Integer Liner Programming* (ILP) is notoriously time consuming (even with *branch and bound* techniques)
- ILP only minimizes the *additional* total bandwidth consumption by a new request, but *not the overall* badnwidth consumption by *all the connections*.

Our Solution: APF-based heuristic with Potential Backup Bandwidth

- Similar to the APF heuristic (polynomial time)
- *But*, in selecting the AP first, each candidate link *e* will be assigned a cost $w+\beta_e(w)$ where $\beta_e(w)$ is
  - the *potential (yet-to-be-incurred) backup bandwidth*
  - proportional to *w* and the total bandwidth already allocated on link *e to existing APs*
  - obtained through rigorous statistical analysis of experimental data
- Runs *faster* than the ILP based approach and yields *a lower overall bandwidth consumption too!*

Other/Ongoing Research

- Trap Avoidance for APF based heuristics
  - May not be able to find a disjoint BP for the given AP even though a disjoint AP/BP pair does exist
- PROMISE: Protection with MultI-SEgments
  - is more bandwidth efficient and recovers from a failure faster than shared path protection
- Protect Against Dual and Multiple Failures
  - dealing with shared risk link groups (SRLGs)
  - *recovery policies* (which BP to use to recover the first/second failure) and their effects

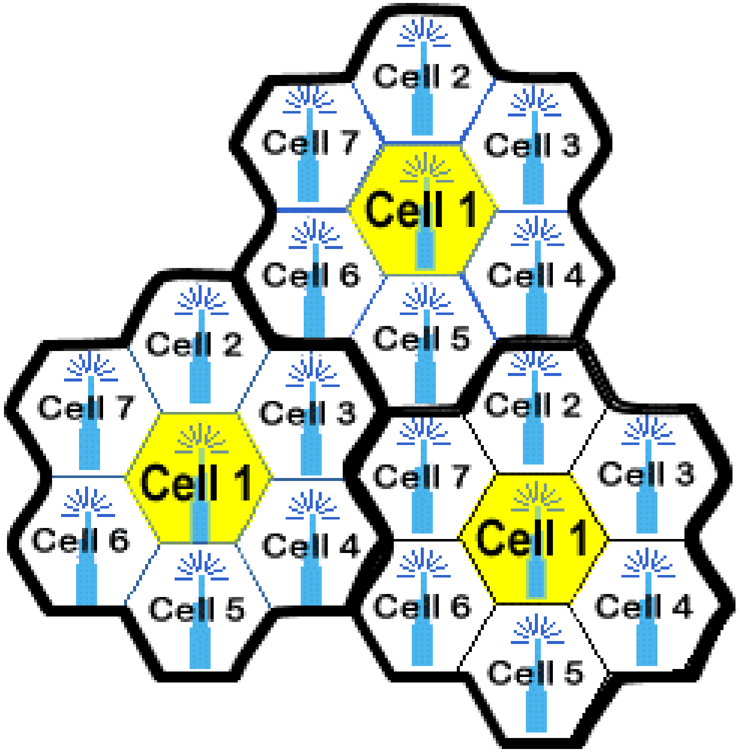
Heterogeneous Wireless Technology

Overlay and Integration of :

- Sensors: ultra wideband /pulse radios
- Personal Area Networks (PAN): Bluetooth, IR…
- Wireless LAN: 802.11 (Ad hoc or Infrastructure)
- Cellular systems (3G and beyond): W-CDMA …
- Satellite communications: GPS, GEOS and LEOS
- Broadband Wireless: free-space lasers for first/last mile applications

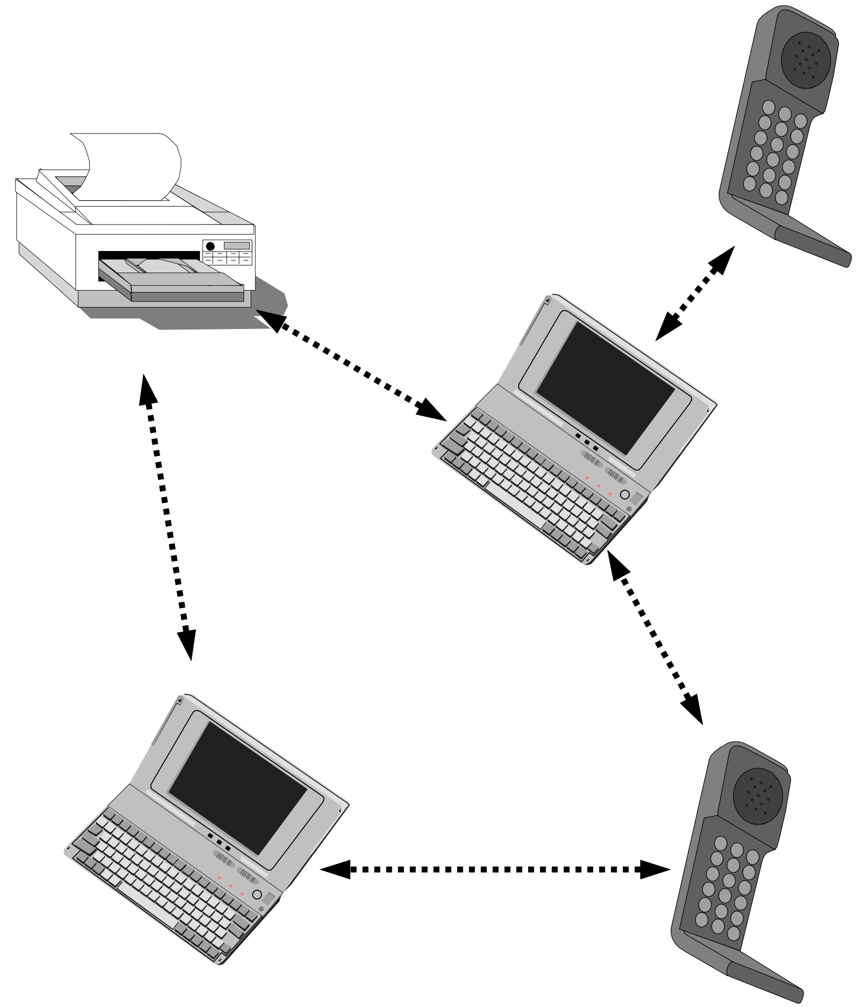
Existing Cellular Systems

- wide coverage and good scalability
- low data rate and limited capacity (or congestion) due to interference
  - each cell has a subset of channels to facilitate their reuse in cells far away, but can't access available channels in nearby cells.



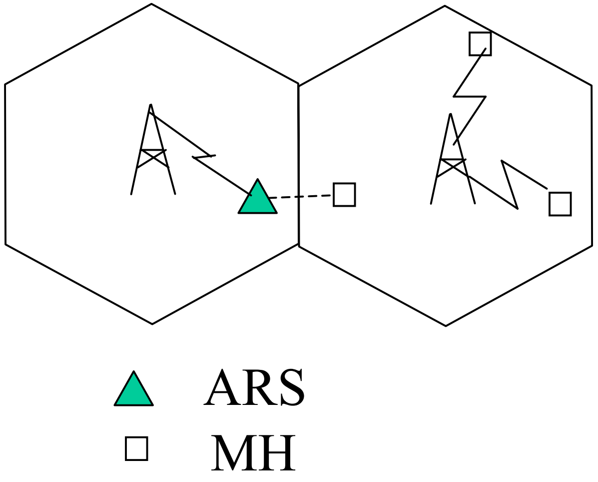
Ad hoc Networking

- No base station or access point (infrastructure-*less*)
- Easy to deploy and high data rate (Mbps and above)
- Limited coverage and scalability



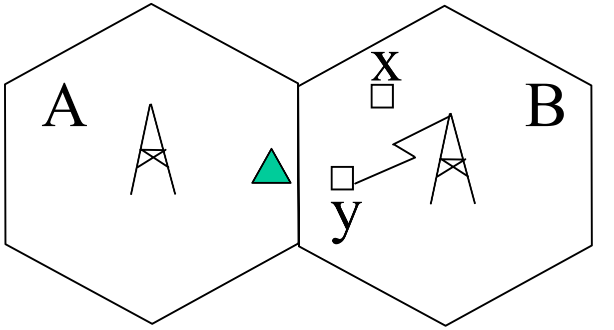
Example: Integrated Cellular and Ad-hoc Relaying (iCAR)

- ARS: Ad hoc Relaying Stations
- MH: Mobile Host (e.g., cell phone)
- Each ARS and MH has two interfaces (cellular and relay)
- ***Primary Relaying*** for *blocked* new or hand-off calls in a congested cell (at right) to a non-congested cell (at left)

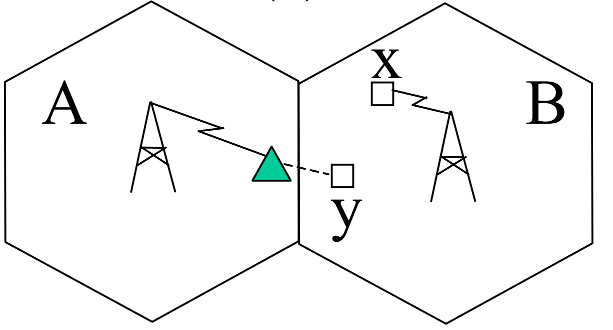


Secondary Relaying

- primary relaying fails:
  - *X* not covered by ARS
  - Reachable cell (e.g., C) is congested too
- **Secondary Relaying**: free the channel of an active MH ***Y*** by relaying its call to a neighboring cell A



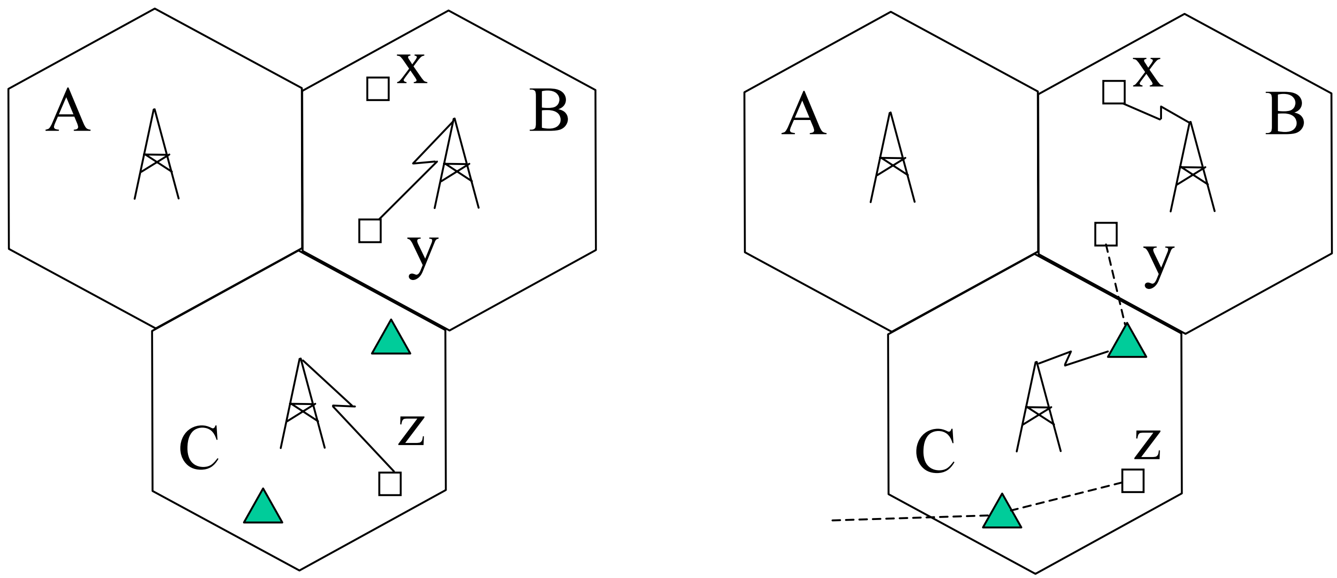
(a)



(b)

Cascaded Relaying

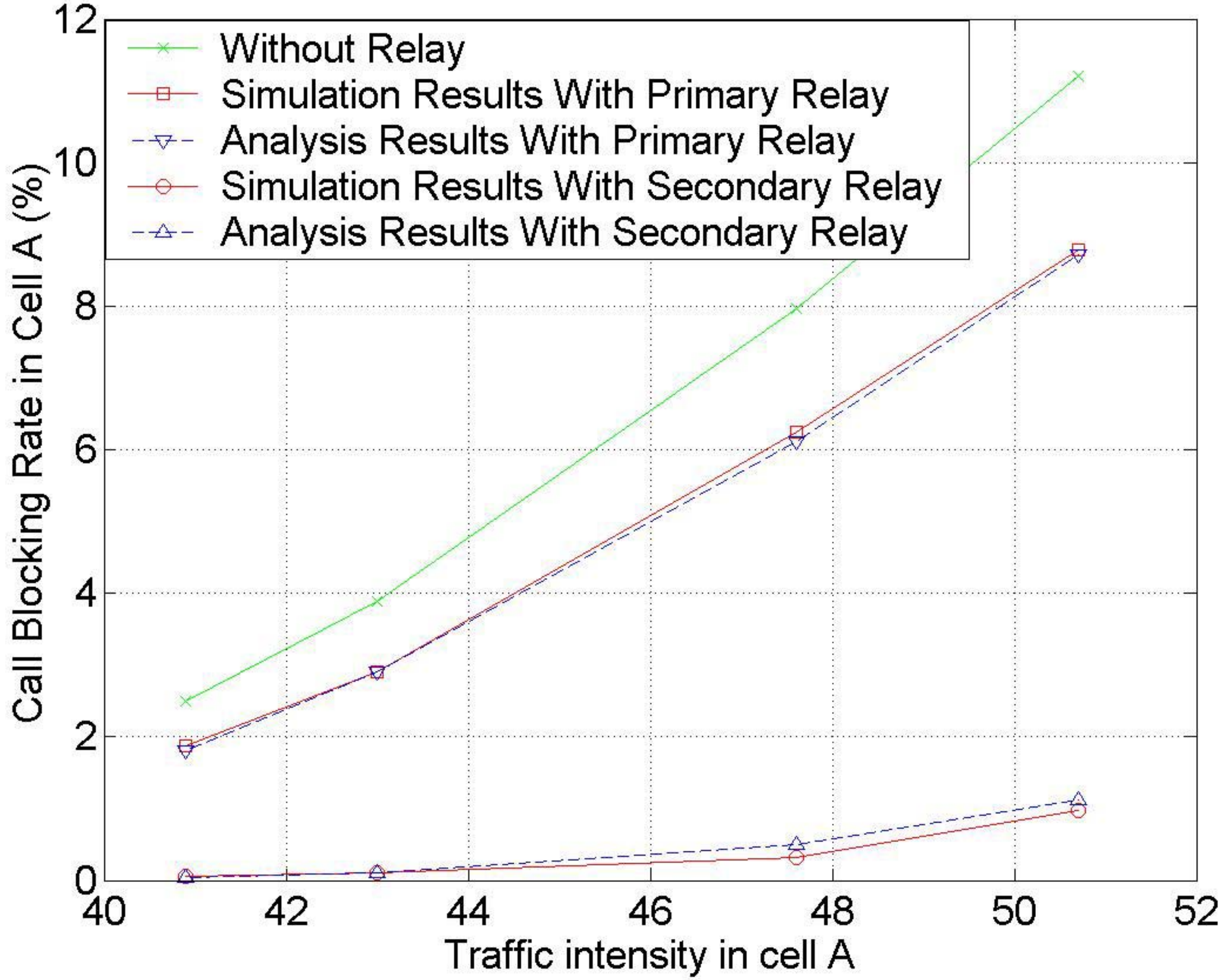
- MH *Z* releases its channel to MH *Y*, which in turns release its channel to MH *X*:



Main Results

- Theorems: iCAR does more than load-balancing
  - call blocking is minimized when the traffic load is balanced among all *n* cells in a conventional cellular system
  - the blocking probability in an ideal iCAR is even lower
- Formula to determine the maximal number of ARS's needed for full or just edge (boundary) coverage
- Develop strategies to place a limited # of ARS's
- Obtain the call blocking probability through analysis and simulation

Simulation and Analysis Results



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Other/Ongoing Research

- Use cellular systems to help Ad hoc networks
  - wide coverage, centralized/global knowledge and authentication/signaling capability
- Integrating other technologies such as broadband wireless, sensors, Bluetooth, 802.11 etc
- Energy efficient routing
- TCP/IP over wireless medium
- Wireless security and survivability

Summary: Opportunities and Challenges

- Research on Optical Networks, Wireless Networks and Internet (including TCP/IP/G-MPLS)
- Network Architecture and Protocol Design
  - scheduling, routing, medium access control, signaling
  - Algorithm, Graph, Information & Communications Theories
- Performance Evaluation
  - Simulation (programming yourself or using existing packages)
  - Analysis: probability /stochastic process (e.g., Markov Chain)
  - Integer Linear Programming formulation (for optimization)
- Graduated 8 PhDs and dozens of MS students (employed by universities and major networking companies)
  - many of them have published papers (journals/conferences) and several have filed patent applications.
- Currently about 10 Ph.D students in LANDER – open to a few good PhD students