Rural Area Wireless Mesh Networks For The Developing World

Major Area Exam

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Digital Divide

the world can be divided into those who do and those who do not have access to and the capability to use modern information technology

Basic human needs may not be satisfied, but
“We believe that ICT
(Information and Communication Technologies) can
greatly help in the provision for such needs”

UN ICT Task Force, 2002

The solution:

satisfies communication needs
cheap
easy to implement
robust
user friendly
self-sustainable
not hampered by the bureaucracy

We already have something similar in our offices / homes / coffee shops

Presentation Roadmap

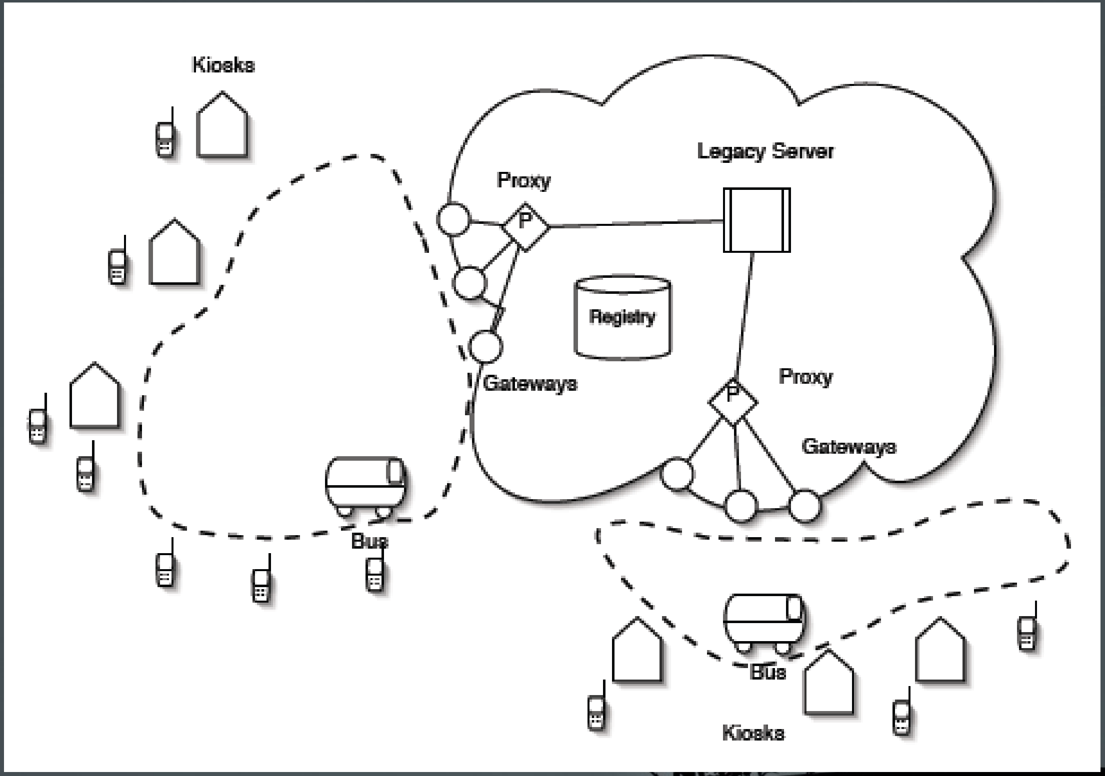
- **Existing rural area wireless network deployments**
- Problem aspects on various layers:
  - MAC
  - Routing
- Energy efficiency
- Performance measurement and network monitoring
- Maintaining sustainability

Existing Rural Area Wireless Network Deployments

- Kiosk-oriented networks
  - SARI (Sustainable Access in Rural India) Project [Kumar 06]
    - Providing the Internet and various governmental services to remote villages
    - Relatively short range links (~10km)
    - Microeconomic business model

Existing Rural Area Wireless Network Deployments

- Kiosk-oriented networks
  - KioskNET [Guo 07] – mechanical backhaul
    - Providing delay-tolerant networking to remote areas
    - Data ferries (buses)
    - Alternative SMS channel
    - User management: users may roam
    - Security



Existing Rural Area Wireless Network Deployments

- Kiosk-oriented networks
  - Aravind eye clinic by TIER Berkeley [Surana 08]
    Long distance 2.4GHz wireless links connecting remote eye clinics

    - 3,000 patients each month
    - Extended to several other locations
    - Fully self-sustainable

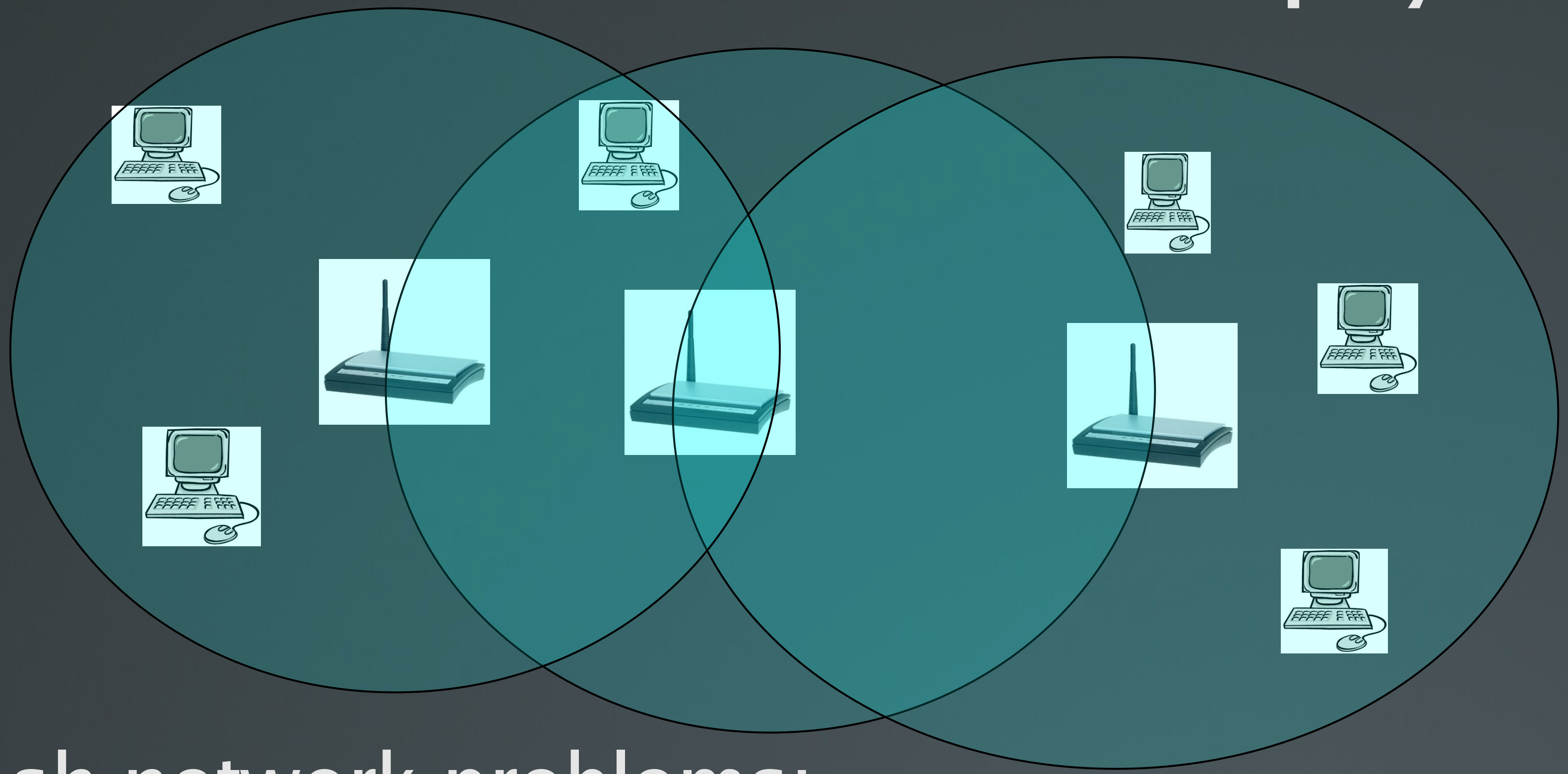
Existing Rural Area Wireless Network Deployments

- Going towards local mesh
  - AirJaldi, Dharamsala
    - Tibetan community in India
    - Mountainous terrain
    - Long distance links and about a hundred low-cost consumer access points
    - Well planned network
    - Estimated 10,000 users

Future Rural Area Wireless Network Deployments

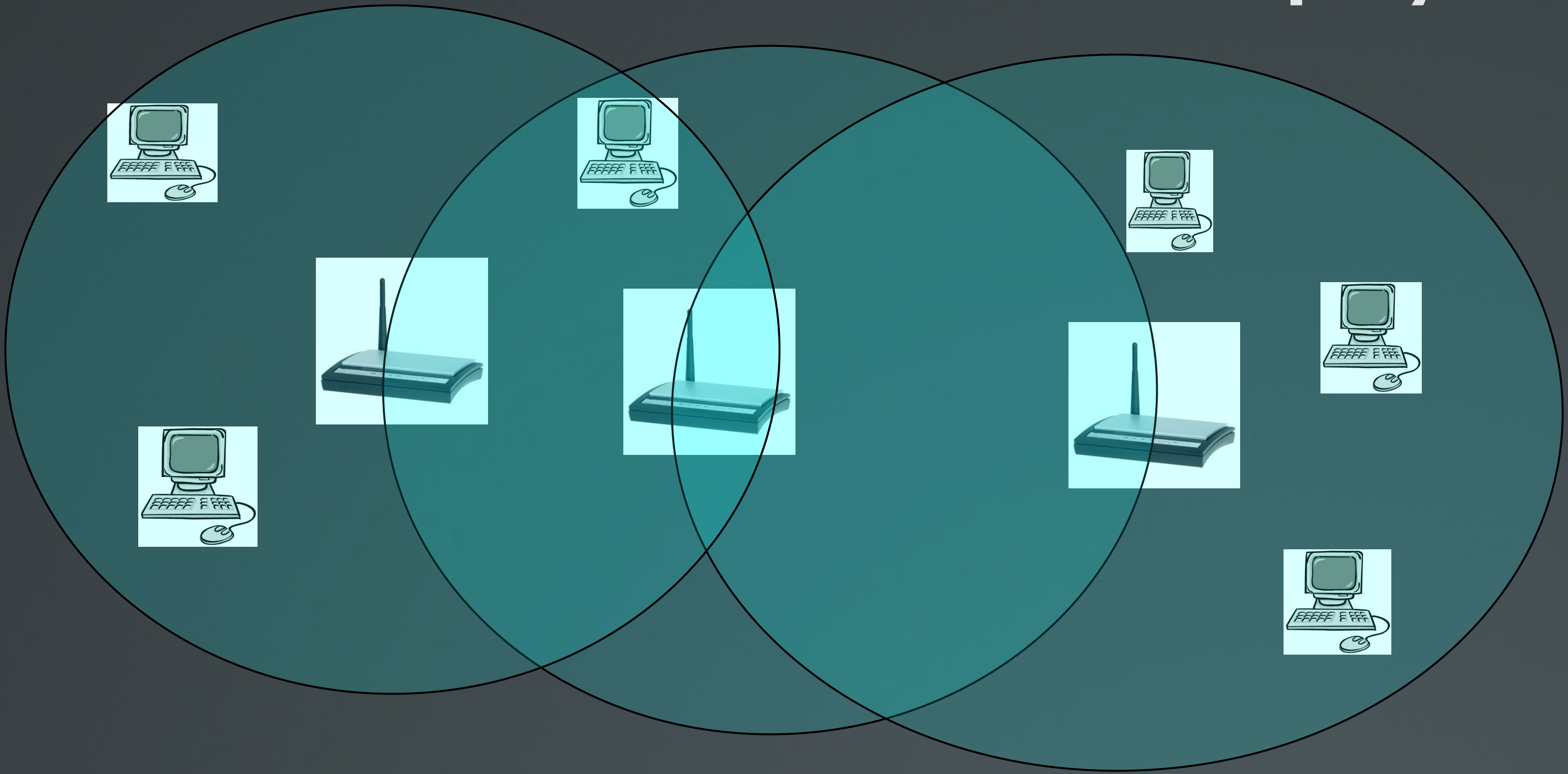
- Local Access First - Justification
  - Not all rural areas are populated densely enough (India-329/km^2 vs Africa-30.51/km^2)
  - The usage patterns reveal:
    - People tend to use provided infrastructure to contact members of their own communities
    - The Rural Telephony project [Sen 06] shows that the people are willing to pay for short casual local calls
  - Kiosks may actually introduce a new divide:
    - Heterogeneous villages
    - Person in charge is unwelcome

Future Rural Area Wireless Network Deployments



- Mesh network problems:
  - Interference
  - Mulit-hop performance (fairness)
  - Quality of service guarantees
  - User mobility

Future Rural Area Wireless Network Deployments



- Rural area network problems:
  - Dominant traffic: voice and video
  - Usage patterns will probably change
  - Power failures
  - Monitoring and Management

Presentation Roadmap

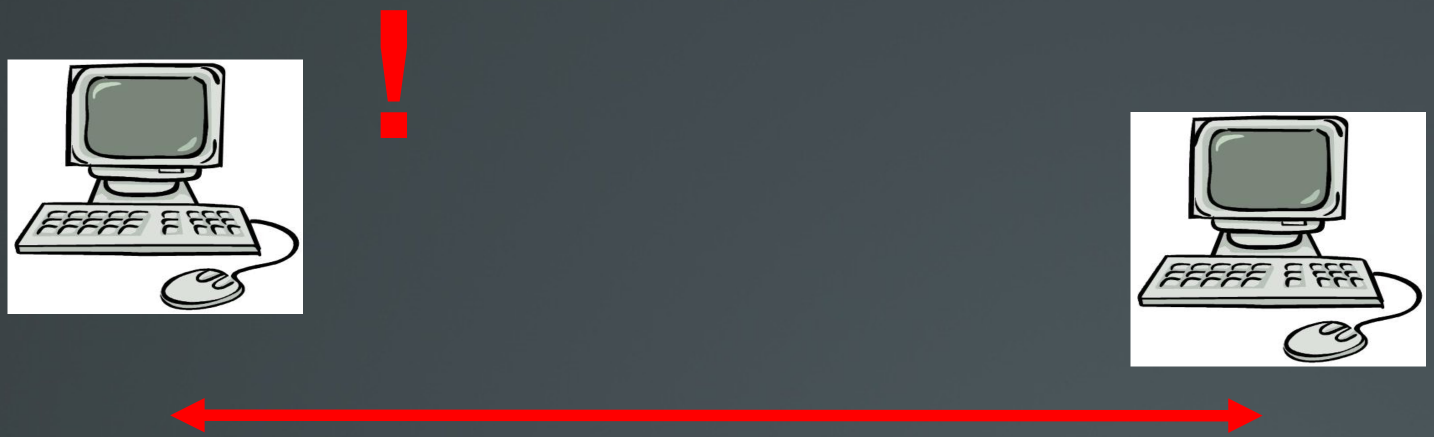
- Existing rural area wireless network deployments
- **Problem aspects on various layers:**
  - **MAC**
  - **Routing**
- Energy efficiency
- Performance measurement and network monitoring
- Maintaining sustainability

MAC Layer - Classification

	Long Distance	Local Area Mesh TDMA
Theoretical Considerations	[Raman 06] [Chebrolu 07]	[Ramantahan 97] [Gronkvist 04]
Implementations	[Raman 05] [Patra 07] [Balakrishnan 07] [Das 07]	[Zhu 01] [Rhee 06] [Lim 06] [Kanzaki 03] [Kanzaki 05] [Rao 05] [Singh 07] [Bahl 04] [So 04]

MAC Layer - Long distance issues

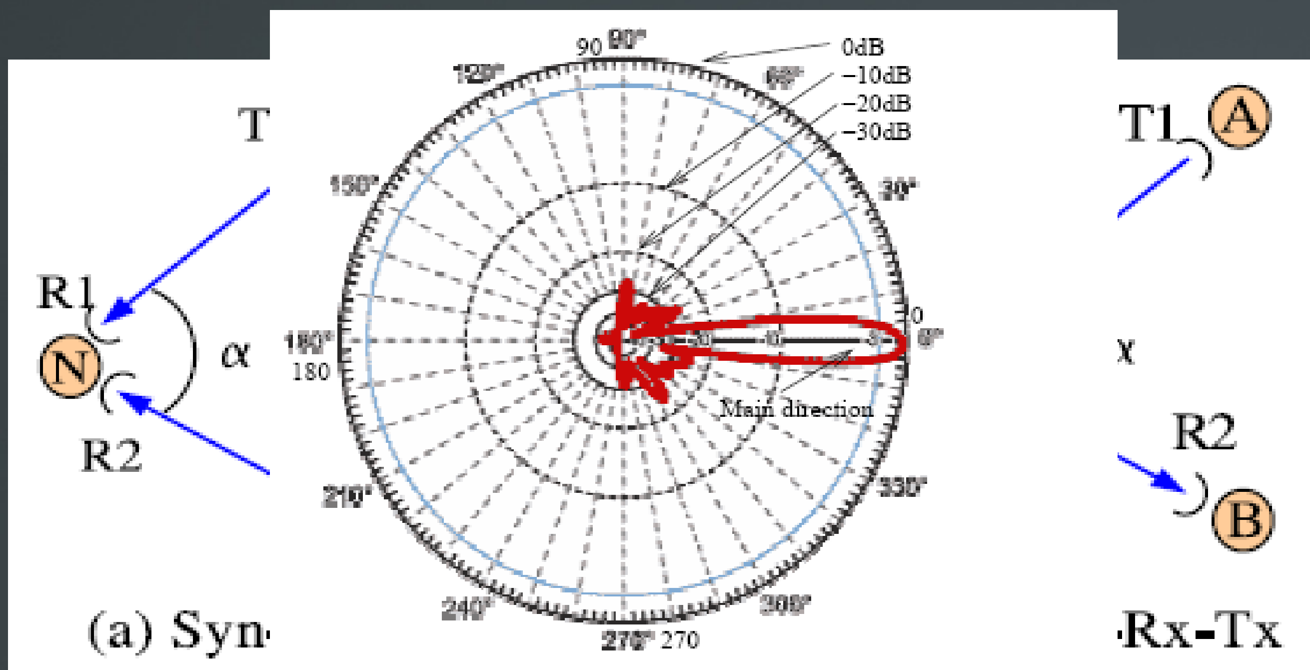
- Standard 802.11
  - Sense for the medium, send a packet, wait for an ACK, if not received in Δt, retransmit



- Problems on Long Distances
  - Carrier Sensing does not perform well when the distance is greater than 15km
  - Timeout is too small, unnecessary retransmissions

MAC Layer - Long distance solutions

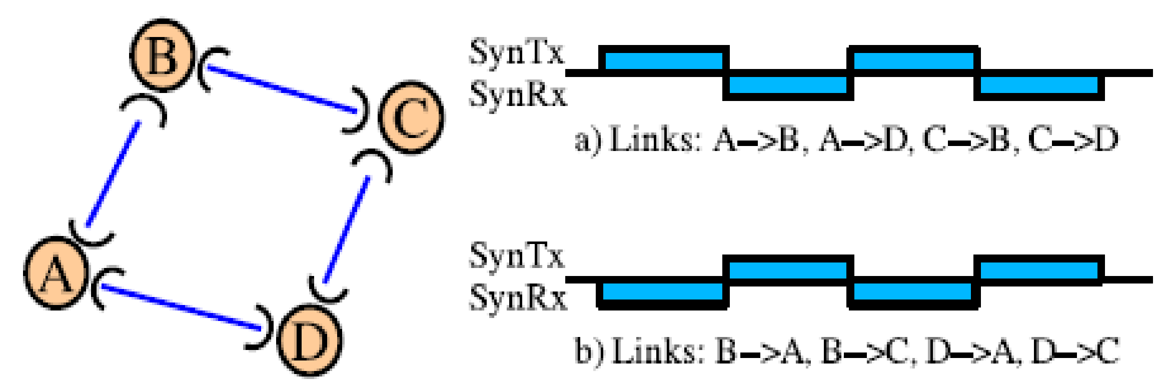
- Turning 802.11 Inside Out [Bhagwat 06]



Spatial radn. pattern of parabolic grid antennae

MAC Layer - Long distance solutions

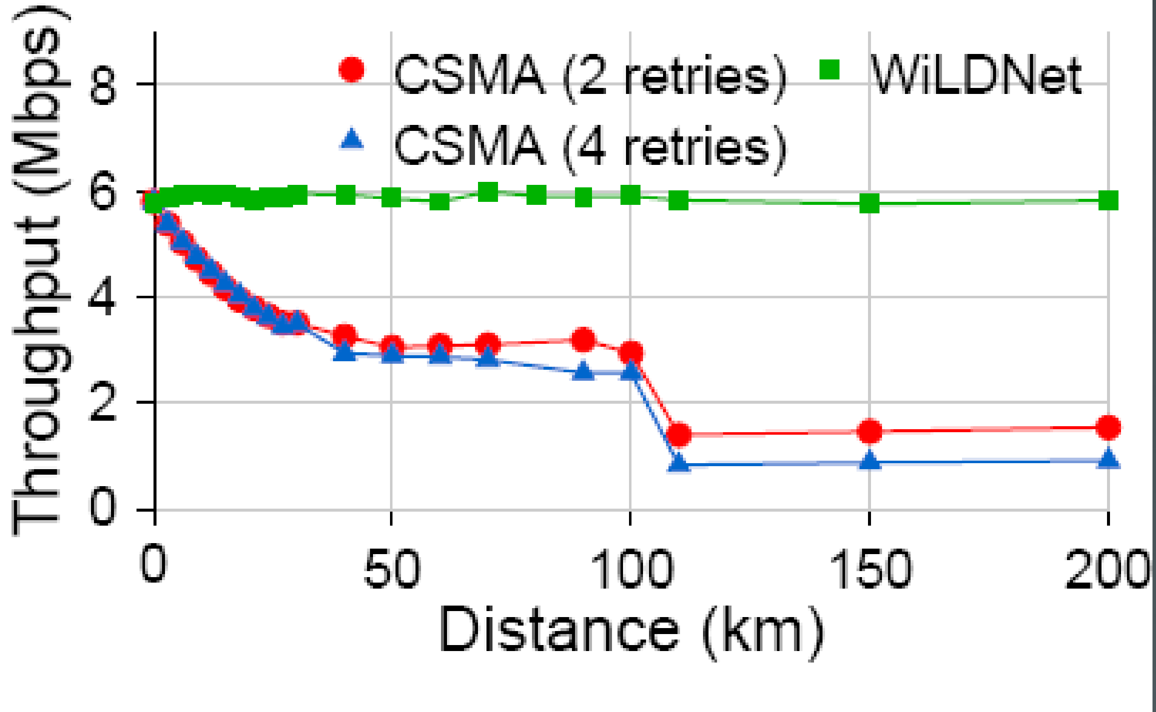
- 2P Protocol [Raman 05]
  - No carrier sensing
  - TDMA-like
  - Disabled ACK
  - Works only in bipartite topologies



- WiLDNet [Patra 07] improves 2P
  - No explicit marker packets but implicit synchronization
  - Adaptive loss recovery: tuning the number of retransmissions
  - Forward Error Correction

MAC Layer - Long distance solutions

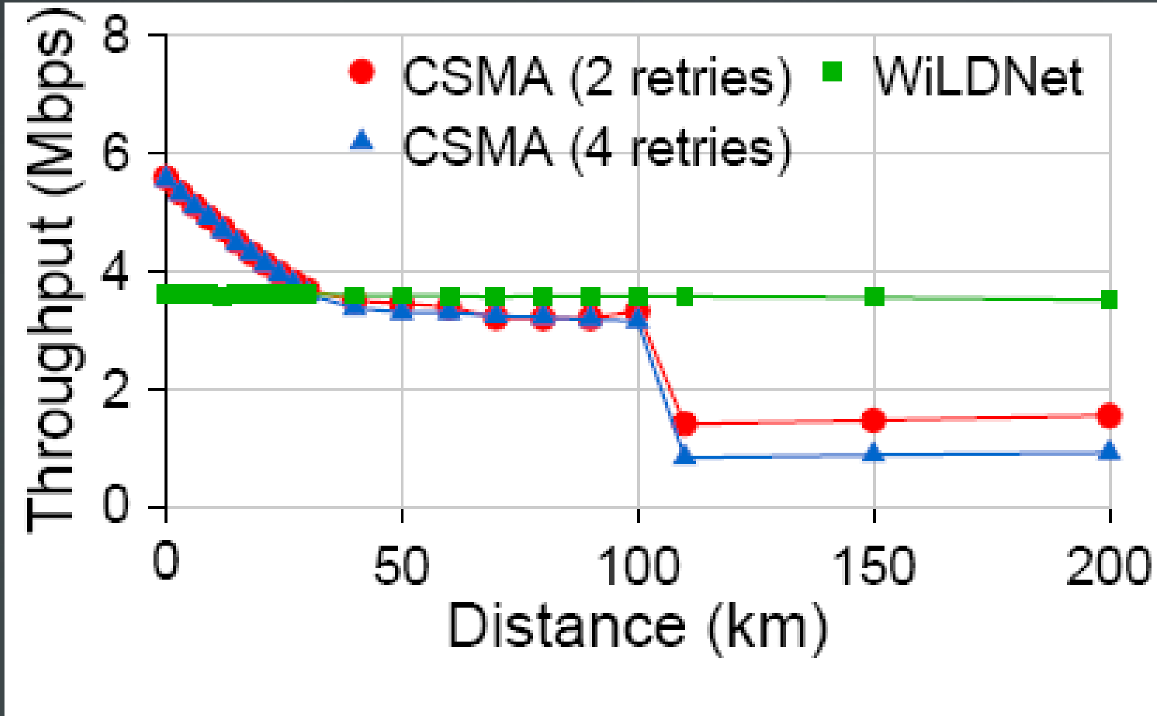
- State-of-the-art performance (WiLDNet)



(b) TCP flow in both directions

MAC Layer - Long distance solutions

- State-of-the-art performance (WiLDNet)

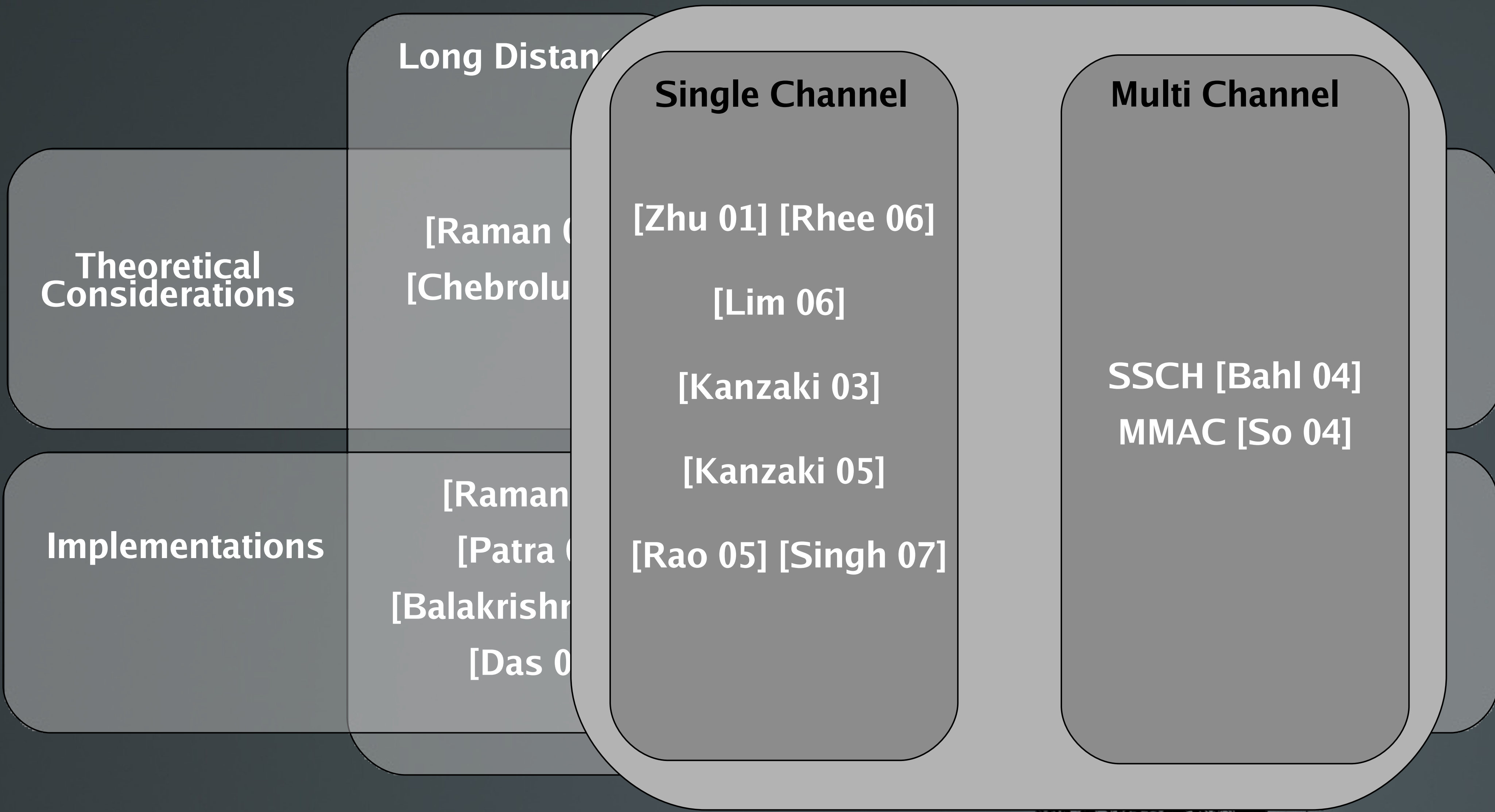


(a) TCP flow in one direction

MAC Layer - Long distance solutions

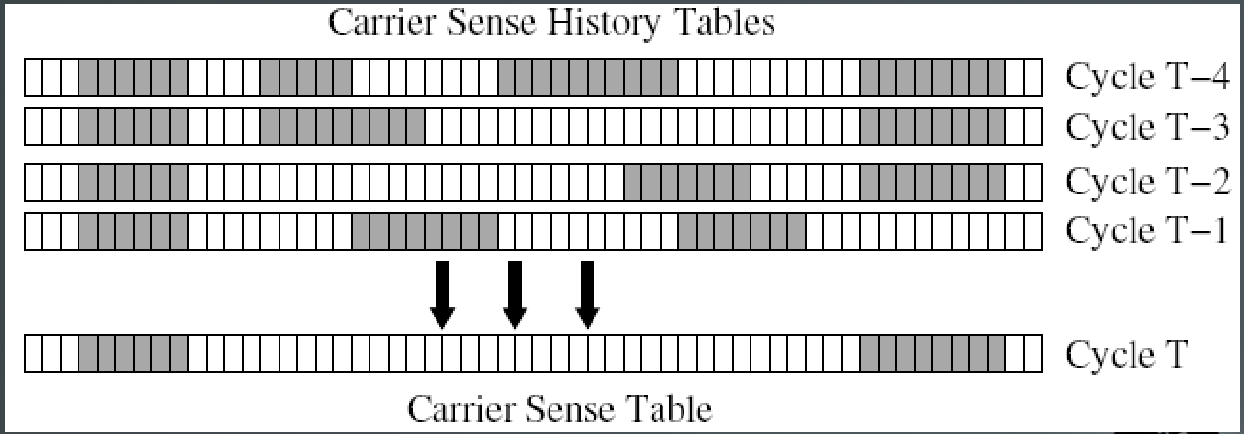
- **Research Challenges:**
  - Better link utilization
  - Enabling arbitrary topologies

MAC Layer - Classification



MAC Layer - Local Mesh

- Sticky CSMA [Singh 07]
  - Dynamic TDMA achieved by sensing the existing transmissions
  - QoS demanding transmissions are periodic (VoIP)
  - Nodes “stick” to the schedule observed in recent past

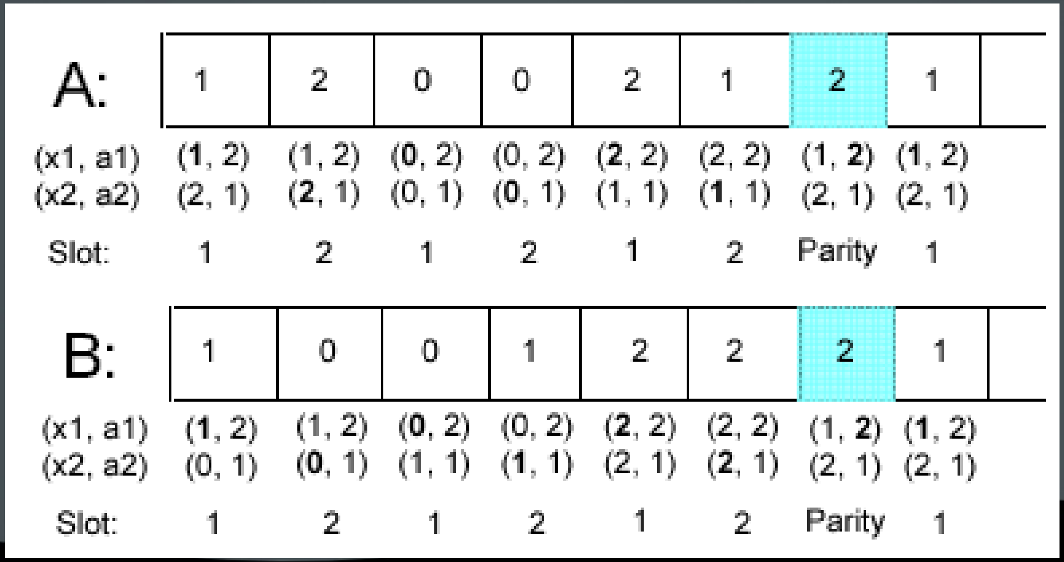


  - The remaining delay insensitive traffic fills the gaps
  - Unfortunately not all real-time flows are periodic - video!

MAC Layer - Local Mesh

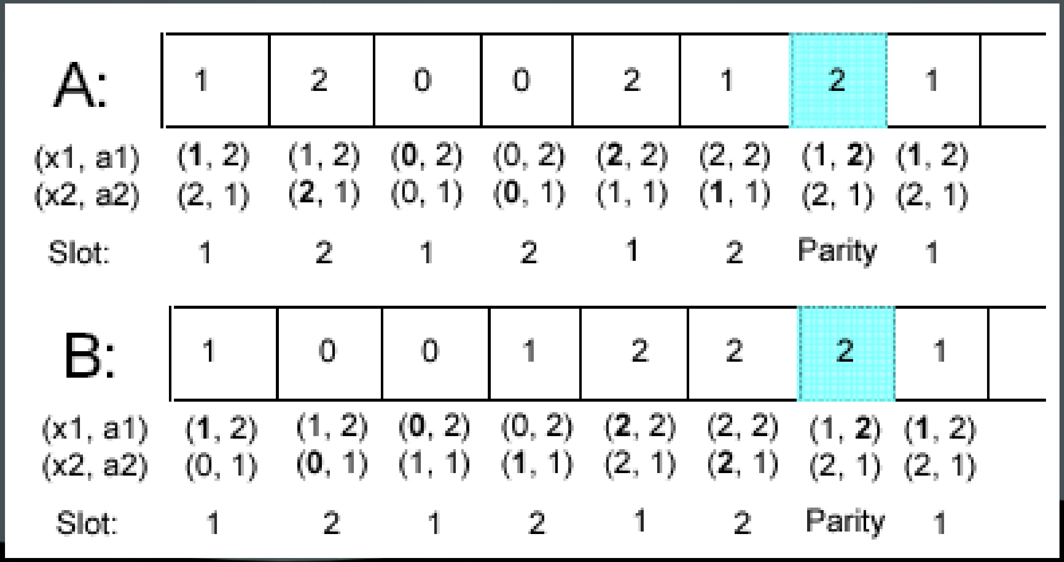
- Multichannel Protocols:
  - SSCH [Bahl 04]
    - Nodes periodically transmit at the different channel;
      The decision on which channel to transmit is deterministic and guarantees that each two nodes will eventually meet at the same channel

      $NewChanel_i \quad (OldChannel_i + Seed_i) \bmod NUMBER\_OF\_CHANNELS$



MAC Layer - Local Mesh

- Multichannel Protocols:
  - SSCH [Bahl 04]
    - Nodes broadcast their schedules so that the others can synchronize the transmissions and continue hopping on the same channel
    - Problems: channel hopping is not instantaneous, loose time synchronization is needed



MAC Layer - Local Mesh

- **Research Challenges:**
  - Traffic prediction
  - Node synchronization
  - Distributed algorithm

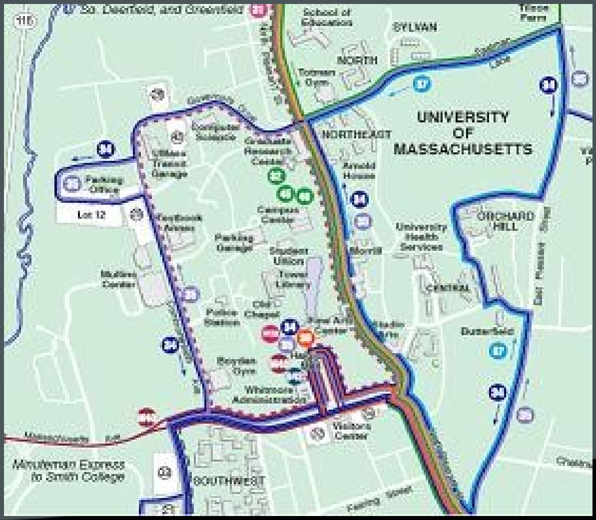
Yet to be developed:

Multichannel (multiradio?) TDMA-like distributed MAC layer protocol with strong real-time flow performance guarantees

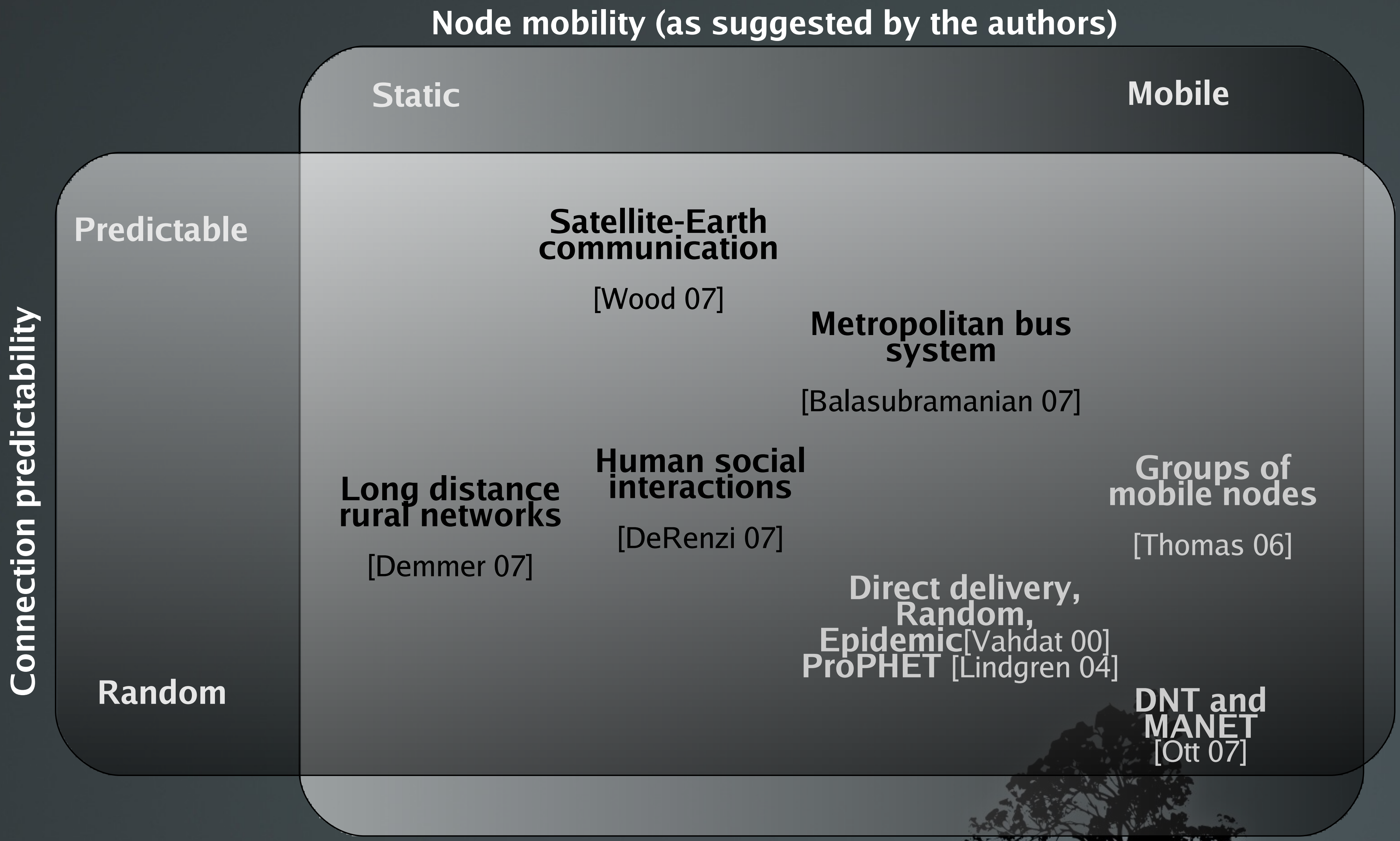
Routing – Delay Tolerant Routing

- DTNs – Link failures are a norm, not an exception
- Observed in different environments:
  - Satellite communications

  - Metropolitan transport systems



Routing – Delay Tolerant Routing

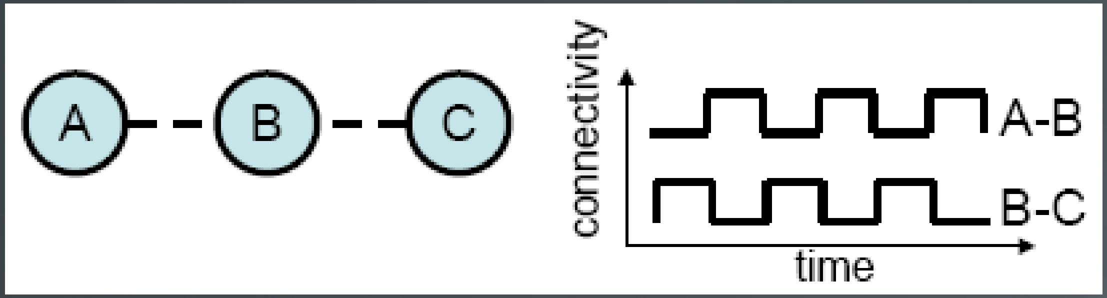


Routing – Delay Tolerant Routing

- DTLSR [Demmer 07]
  - Designed with rural area mesh networks in mind
  - Different than regular DTN routing since the networks are usually static or the movements are predictable
  - Link state algorithms provide enough data about the network "life" to be able to predict temporarily unavailable links
  - Every node has the whole topology so it can be queried

Routing – Delay Tolerant Routing

- DTLSR [Demmer 07]
  - LSA (Link State Advertisement) control data can be transferred by some other mean (e.g. SMS)
  - Each node has its administrative area
  - LSAs have a long lifetime
  - Metric: minimizing estimated expected delay



Routing – Delay Tolerant Routing

- Alternative – Exploit human mobility patterns [DeRenzi 07]
  - Location profile is maintained, describing where the device has been roaming
  - When two devices meet they analyze the probability of the other one returning to a connected environment

Routing – Delay Tolerant Routing

- **Research challenges:**
  - Identifying the sufficient level of replication
  - Defining the right routing metric
  - Common files distribution (Wikipedia, software updates)

Presentation Roadmap

- Existing rural area wireless network deployments
- Problem aspects on various layers:
  - MAC
  - Routing
- **Energy efficiency**
- Performance measurement and network monitoring
- Maintaining sustainability

Energy Efficiency - Fight on Many Fronts

	Energy Efficient Protocols	
Application Layer	[Haratcherev 07]	Load balancing Sending only necessary data
Network Layer	[Cheng 03] [Doshi 02]	Minimum energy paths Efficient broadcast Smart Balancing
MAC layer	[Singh 98] [Hohlt 04] [Buettner 06]	Prevent collisions Allow sleeping periods
Physical Layer	[Lin 06] [Nedevschi 07]	Rate adaptation Transmission power
Powering Off	[Chen 02] [Shih 02] [Agarwal 07] [Jardosh 07] [Mishra 06]	Turn off the equipment when not in use Wake up on time to receive

Energy Efficiency

- Investigating Energy Consumption [Feeney 01]

	measured	spec
Sleep Mode	10mA	10 mA
Idle Mode	156 mA	n/a
Receive Mode	190 mA	180 mA
Transmit Mode	284 mA	280 mA
Power Supply	4.74 V	5 V

WaveLAN card measured performance (11Mbps)

Wireless Card Only = 1W max

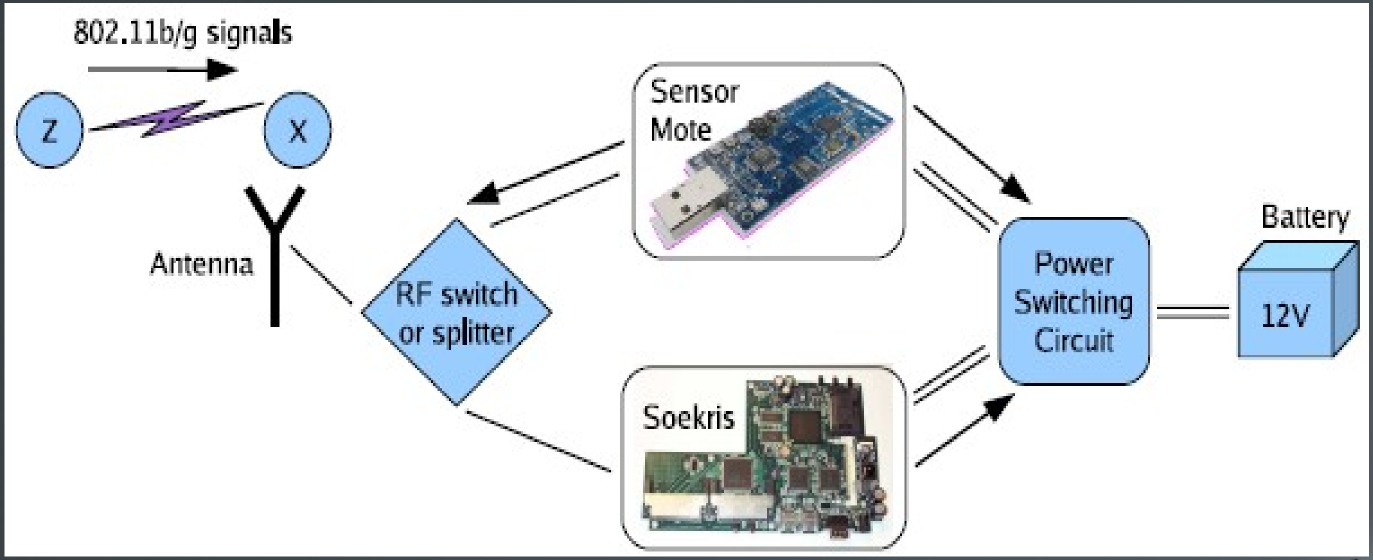
- Broader Picture [Mishra 06]

Atheros card: 802.11a				
No transfer	0.23A	27.60V	6.35W	–
Soekris rcv'ing	0.23A	27.60V	6.35W	7.89Mbps
Soekris sending	0.30A	27.50V	7.95W	7.71Mbps
	Current	*Voltage*	*Power*	*Thrpt*

Wireless Card and Soekris Board = 8W

Energy Efficiency

- Powering Off
  - Wake on WLAN [Mishra 06]
    - 802.15.4 sensor motes can register WiFi communication
    - The incoming traffic powers on the node



    - Drawback: it takes up to 50 seconds to power up a Soekris board

Energy Efficiency

- Potential Problems
  - Why should I spend energy routing your traffic?
    - Free-Riding – if a member of a network obtains the benefits from the group but does not bear the proportional share of the cost of providing the benefits
  - To avoid free-riding [Albanese 85] suggests building various private goods that reflect the participation in building the public good
  - Incentive system should be in place; the participation should be identifiable easily

Energy Efficiency

- **Research Challenges:**
  - Different power saving techniques depending on current energy levels and applications used
  - Encourage cooperation among nodes
  - Better powering on/off hardware (out of scope)

Presentation Roadmap

- Existing Rural Area Wireless Network Deployments
- Problem aspects on various layers:
  - MAC
  - Routing
  - Energy Efficiency
- **Performance Measurement and Network Monitoring**
- Maintaining Sustainability

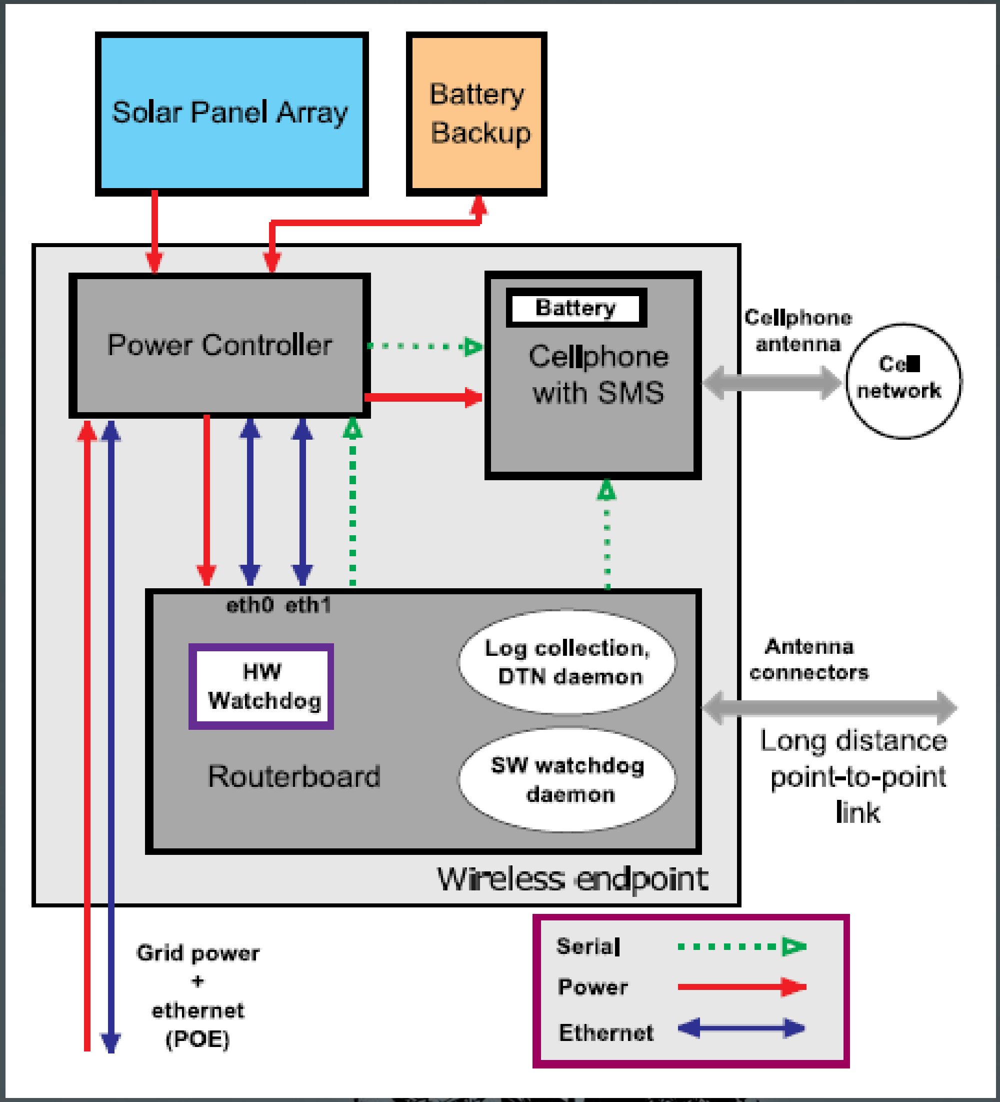
Performance Measurements and Monitoring

- Monitoring Problems:
  - Local staff tend to have limited knowledge of wireless networks
  - Fluctuating power quality causes hardware failures

  - Many wireless nodes are in remote locations
  - The failure of a single link may make parts of the network inaccessible remotely

Performance Measurements and Monitoring

- Monitoring Solutions [Surana 07]
  - Hardware and software watchdogs do not share the same fate with the networking devices
  - Problems should be predicted so the number of visits can be lowered



Performance Measurements and Monitoring

- **Research Challenges:**
  - Necessary parameters that should be monitored
  - Lightweight monitoring system
  - Decentralized system

Maintaining Sustainability

- Making a self sustainable rural area network is hard, but the following may help:
  - Involve local economies
  - Get support from the community leaders
  - Establish the network as a community asset rather than as a mere commercial enterprise
  - Designing an adequate interface for different local languages and illiterate people

Maintaining Sustainability

- Additional Problems
  - Experienced staff is hard to find, and volatile
  - Novice users are prone to online scams, viruses
  - Payment may become irregular - seasonal work produces seasonal income, however, most Internet providers do not tolerate late fees
  - A local digital divide may emerge if the network is not planned properly

Open Problems

Improved long distance MAC protocols' performance
Support for diverse topologies

High capacity multichannel/multiradio TDMA MAC layer protocol with strong real-time flow performance guarantees

Resource aware delay tolerant routing and content distribution

Improved energy efficiency on all levels

Lightweight, robust network monitoring framework

Conclusion

Designing technologies that can radically impact peoples' lives requires a complete understanding of consequences and a careful of interaction of all relevant sciences

Conclusion

Any other approach would be irresponsible

Thank You!

Questions?

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MAC Layer - Local Mesh

- TDMA Solutions
  - Unified Framework [Ramanathan 97]: graph coloring approach, theoretical limits for TDMA throughput with perfect synchronization and centralized oracle in place
  - A variety of protocols proposed: FPRP [Zhu 01], ASAP [Kanzaki 03]
  - Even more for sensor networks: S-MAC, X-MAC
  - The main problems are:
    - Node synchronization (can be achieved by a GPS device)
    - Traffic prediction
    - Distributed algorithm

Energy Efficiency

- Fight on Many Fronts
  - Rate Adaptation
    - Lower the rate and get better SNR for the same transmission power; the rate fallback should not introduce excessive delay [Lin 06]
  - MAC Protocols
    - Turn off the wireless interface if the transmission is going to experience interference or there is nothing to be transmitted [Singh 98]
  - Routing
    - Efficient broadcast [Cheng 03], minimum energy paths [Doshi 02]
  - Application
    - Load balancing, sending only necessary data (lower quality voice and video)

MAC Layer - Long distance solutions

- RTDMA-DA [Das 07]
  - More flexible slot reservation, but a strict grid topology
- Link Dynamism [Balakrishnan 07]
  - Adjusting timeouts, interframe spacing, slot duration by analysing observed performance (RTT)

Routing – Delay Tolerant Routing

- Unpredictable Mobile Networks
- Integrating DTN Routing and AODV [Ott 06]
  - Depending on the application and the connectivity, the node uses AODV or DTN routing
- DTN Routing as a Resource Allocation Problem [Balasubramanian 07]
  - Metropolitan bus system equipped with 802.11 radios
  - The routing algorithm minimizes either the average delay, missed deadlines or the maximum delay

Routing – Delay Tolerant Routing

- Unpredictable Mobile Networks
- [Song 07] Survey:
  - Direct Delivery
    - A node sends a message only when it encounters the receiver
  - Epidemic
    - Send a copy of a message to anyone in the range
  - Random
    - A message is forwarded with a certain probability (0,1)
  - PRoPHET
    - Use the history of past encounters to infer if a message should be forwarded to the node or not
  - Link State
    - Inter contact duration; messages are forwarded to the node that has the path with lowest link-state weight

MAC Layer - Local Mesh

- 802.11e – QoS Amendment to the standard
  - EDCF instead of DCF
    - Transmit Opportunity (TXOP)
  - HCCA instead of PCF
    - For infrastructure networks; contention free periods
- 802.11e – Drawbacks:
  - EDCF does not give any guarantees for prioritized traffic, collisions still exist, even if the number of available flows is capped
  - HCCA: The clients may request resources only in a period which is not contention-free, thus there is no guarantee that they will be granted resources on time

Routing – Delay Tolerant Routing

- Content Dissemination
  - Large, common files (Wikipedia, software updates) should be effectively distributed in the network
- CodeTorrent [Lee 06]
  - Network-coding-based swarming protocol
  - Designed for loosely connected vehicular networks

Performance Measurements and Monitoring

- Results from the deployments
  - Power glitches result in hardware failure or unexpected component behavior (router resets, wireless card on but not transmitting, and others)
  - External interference is varying and highly influences link quality
  - The link abstraction does hold, multipath fading is not a problem
  - Rate adaptation can be done based on SNR values
  - Weather conditions do not impact the performance
  - Antenna placement on a single node should be considered carefully

MAC Layer - Local Mesh

- Overlay MAC [Rao 05]
  - Implements MAC layer functionality without modifying the layer
  - Performs as a dynamic TDMA-based protocol
  - Needs (loose) synchronization among nodes