A Research Overview of the Telecommunication Networks Group Technical University Berlin

Holger Karl

Outline

- Group overview
- TCP in wireless networks (ReSoA)
- Capacity in ad-hoc networks

Organizational Structure

Technical University Berlin

Faculty of Electrical Engineering and Computer Science

Institute for Tele-communication Systems

Telecommunication Networks Group
Head: Prof. Dr.-Ing. Adam Wolisz

TKN Research Vision

- Vision: **AMICA** – Adaptive, Mobile Internet-based Communication Architecture
  - Terminals use several wireless technologies (overlay networks)
  - Ad-hoc networking principles are used between end systems
  - Access points are connected by high-speed, typically optical links
  - Communication is based on IP-style interfaces and protocols
- Research focus: Architecture and protocol for mobile communication systems
  - Development of new protocols, algorithms, architectures, …
  - Performance evaluation using simulation and prototypes

TKN Research Groups: Overview

- TKN
  - Wireless link layer
  - Ad-hoc networks
  - Energy efficiency in wireless networks
  - Transport protocols for mobile networks
  - Mobility mechanisms in IP networks
  - Active networking for mobility/security
  - Application-aware wireless networks
  - Security
  - Optical networks

TKN Research Groups: Brief description

- Active Networking for mobility/security
  - Protocol downloading for mobility, especially dynamic installation/setup/configuration of performance enhancing proxies
  - Use active networking in order to enhance security
  - In network routers as well as end systems

- Application-aware wireless networks
  - Application-dependent use of redundancy in the wireless link
    - Example: Use more redundancy for packets that are important to a voice codec's perceived quality
  - MPEG-4 transport over wireless links

TKN Research Groups: Brief description

- Ad-hoc networks
  - Improving capacity and energy-efficiency in cellular networks by ad-hoc-based multi-hop routing
    - Joint power and rate adaptation
    - Topology and routing control
  - Ad-hoc extensions to HiperLAN/2

- Energy efficiency in wireless networks
  - Modification of WLAN protocols (IEEE 802.11), e.g. dynamic packet length adaptation

TKN Research Groups: Brief description

- Mobility mechanisms in IP networks
  - Multicast-based handover support
  - QoS support during handover (signaling protocols)
  - Integrated authentication/authorization mechanisms
  - End-to-end handover protocols

- Security
  - Authentication/authorization in mobile networks
  - Location privacy issues
  - Secure downloading and execution of protocols in active networks

TKN Research Groups: Brief description

- Transport protocols for mobile networks
  - Interface-neutral transport protocol adaptation for wireless links (e.g., performance enhancing proxies)
  - Reuse of congestion information

- Wireless link layer
  - Stochastic channel models for wireless links
  - Real-time wireless communication in industrial environments
  - Channel-state-adaptive scheduling of data streams
  - Dynamic use of multiple CDMA codes to support QoS requirements despite intermediate channel outages

TKN Research Groups: Brief description

- Optical networks
  - Optical backbones for wireless communication systems
  - Wavelength division multiplexing-based architectures
  - Goal: Support for Radio-on-the-fiber systems

TKN Research Groups: People

- Active networking for mobility/ security
  - Chen, Eyrich, Hess, Hoene, Schäfer, Schläger
- Ad-hoc networks
  - Hollos, Karl, Kubisch, Mengesha
- Application-aware wireless networks
  - Hoene, Klaue, Rathke
- Energy-efficiency in wireless networks
  - Ebert, Kubisch
- Mobility mechanisms in IP networks
  - Chen, Festag, Fu, Karl, Wei
- Optical networks
  - Kim, Maier, Woesner
- Security
  - Chen, Hess, Schäfer
- Transport protocols for mobile networks
  - Karl, Schläger, Savoric
- Wireless link layer
  - Aguiar, Ebert, Fitzek, Willig

Contact via: http://www-tkn.ee.tu-berlin.de/people

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- Group overview
- *TCP in wireless networks (ReSoA)*
  - *Problem outline*
  - ReSoA architecture
  - Performance results
  - Conclusions
- Capacity in ad-hoc networks

Applications in wireless networks

- Users want to use identical applications on mobile and fixed terminals
  - Web browsing, email, Napster, voice, some multimedia
  - Typical setup: wired backbone, wireless last hop
- Most of these applications rely on reliable data transmission
  - Typically: implemented on top of sockets, use TCP
- TCP's main features were developed for wired networks – how does TCP perform in wireless networks?

TCP in wireless networks

- Wired network: few errors
  - If any errors, due to overload (packet dropped in router)
  - Correct reaction: Reduce offered load – congestion control
- Wireless network: lot’s of errors
  - Correct reaction: retransmit
- TCP interprets random link errors as sign of congestion
  - Offered load is reduced instead of aggressively retransmitting
  - Retransmissions would often have to come from “far” hosts
  - Poor performance is observed in wireless networks

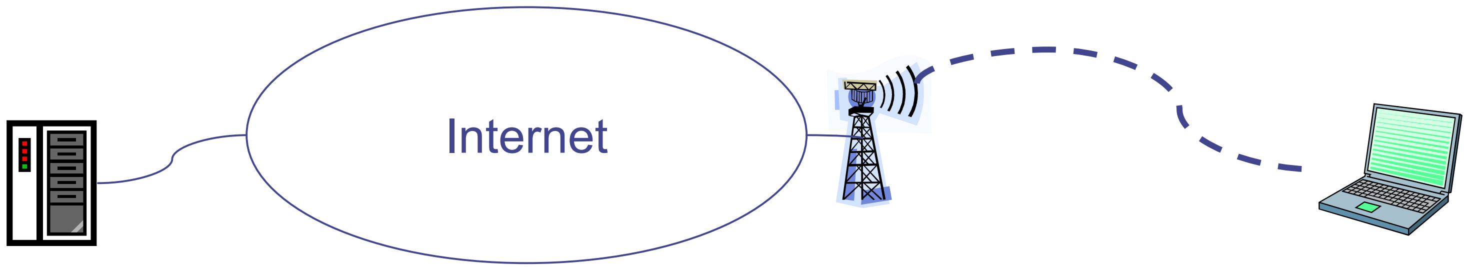
Supporting reliable applications

- Maybe TCP is the wrong protocol to begin with?
  - Designing a new Internet-wide reliable transport protocol is not a realistic goal
  - Problem only rests with the wireless hop anyway
- Maybe applications do not really care about TCP?
  - Applications are interested in having their data transported reliably
  - Interface should remain unchanged
  - Which protocol is used is of no concern
- Transport *service*, not *protocol* is the main issue

Supporting reliable applications

- Sufficient to support well-defined service interface for reliable transport
  - Sockets, in the wired terminal sitting on top of TCP
  - Sockets, in the wireless terminal sitting on top of ???, specifically designed for wireless networks

- How to connect these two parts?



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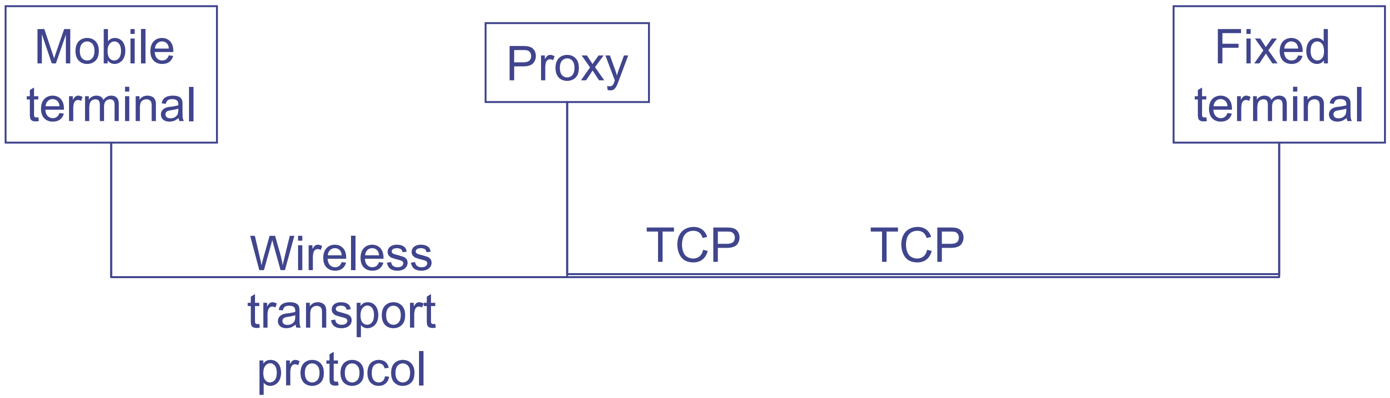
Remote Socket Architecture (ReSoA)

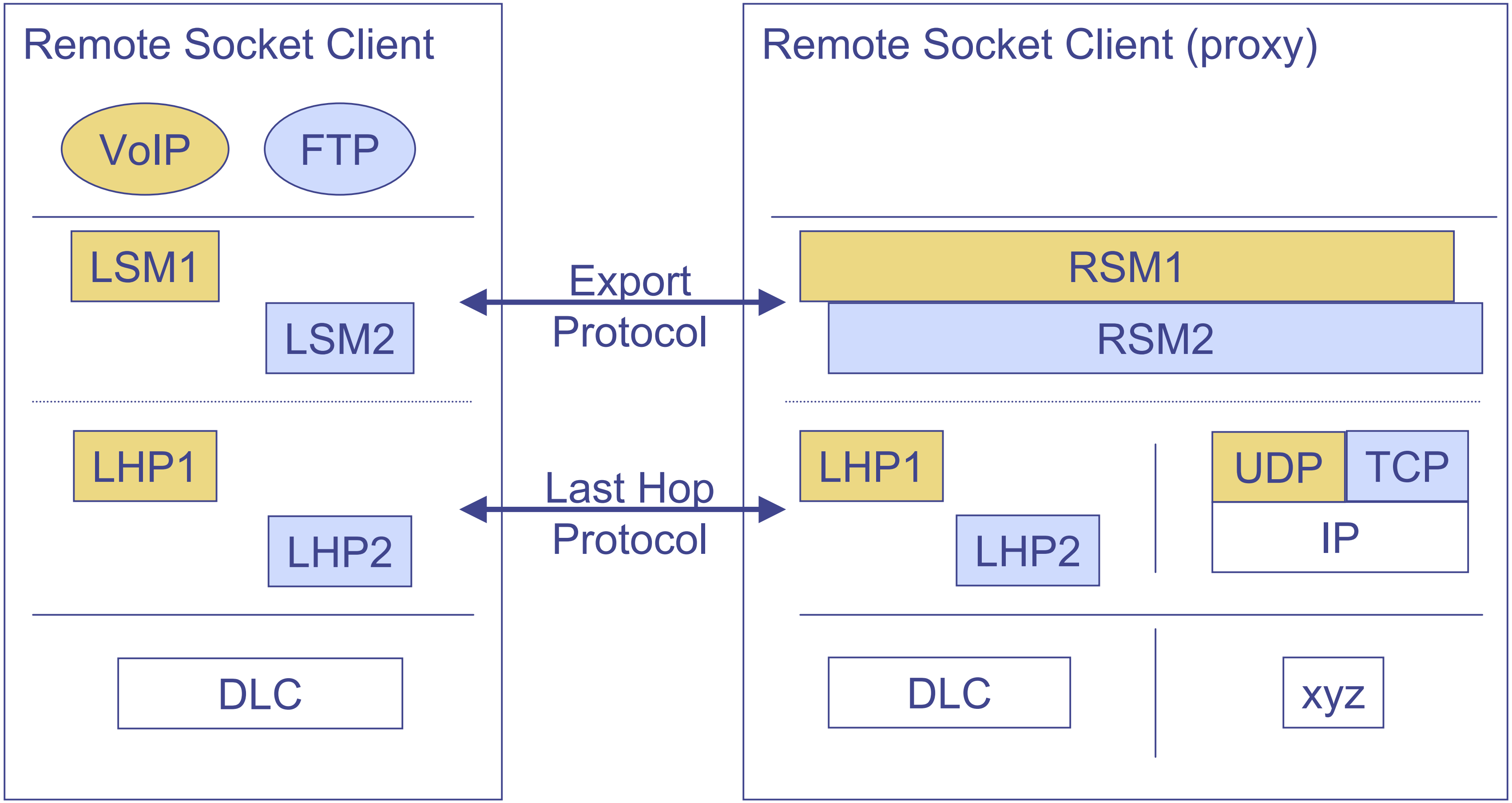
- Our solution: ReSoA
- Splits the Berkeley Socket interface (AF_INET family) into two parts
- Is transparent for the application
  - No modification, no re-compilation of applications
  - Preserves semantic of socket interface
  - Can replace the Internet protocol stack on the end-system
  - Can operate in parallel with Internet protocol stack
- Is transparent for remote end-system

Architecture (I)

- End-to-end TCP unsatisfactory performance
- Use specific transport protocol over wireless hop
- Connecting these two protocols via proxy in wired network



Architecture (II)



LSM: Local Socket Module, RSM: Remote Socket Module, LHP: Last Hop Protocol

Architecture (III)

- LSM-RSM pair implement a socket object
- Export Protocol is used to exchange messages between LSM and RSM
- Export Protocol expects a well defined service from LHP
  - In case of TCP sockets: Reliable
  - In case of UDP sockets: Semi-Reliable, application-dependent
  - It is *not* a split-connection protocol: socket operations are executed remotely
- LHP depends on technology, application, socket type
  - Protocol behavior not part of ReSoA
  - Only service and interface are specified

Export Protocol

- Request-Response Message for socket functions that require a response
  - E.g. `connect` and `bind`
- Request Message for socket functions that do not need a response
  - E.g. `write`
- Control Message
  - State change, send and receive buffer update
- Timer for failure detection

Semantic Issues

- TCP acknowledgments:
  - Data has reached the peer entity
  - Data not necessarily consumed by receiving application
- RFC 793: TCP interface can be implemented in a remote fashion as long as an appropriate protocol is used
- Saltzer et al. in ‚E-2-E arguments…': "*End-to-end reliability can only be implemented by applications*"

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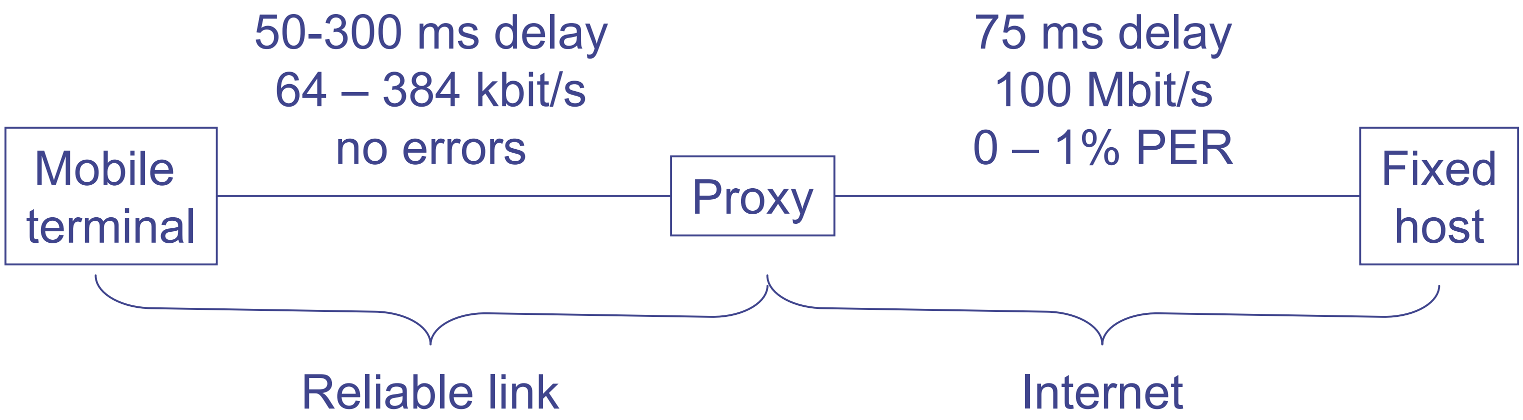
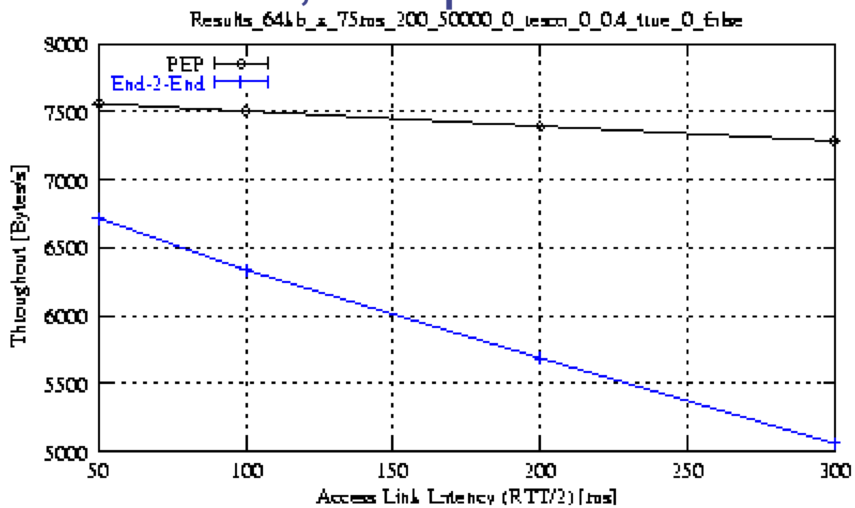
Performance Results

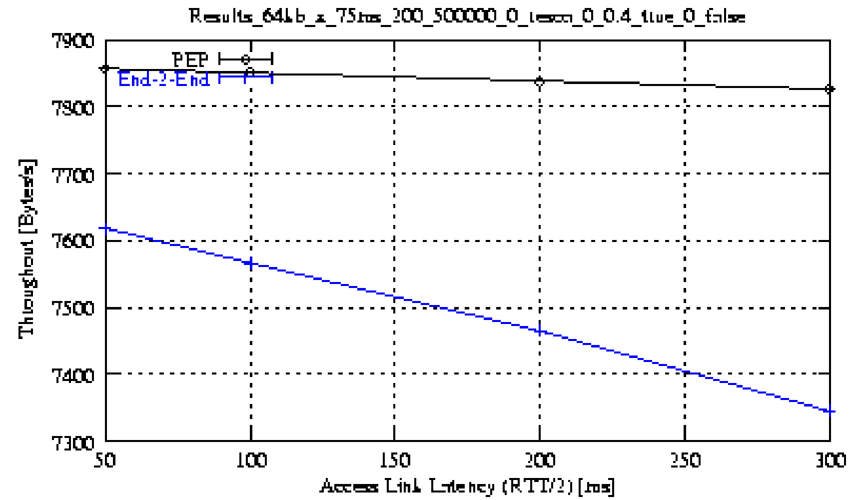
- Experiments with up-to-date wireless equipment is still under way
- Simulation: GPRS-like scenario
  - Proxy far away from mobile terminal, located in gateway to the Internet
  - Reliable link in the radio access network, but long delay
  - Some congestion-based errors in the Internet

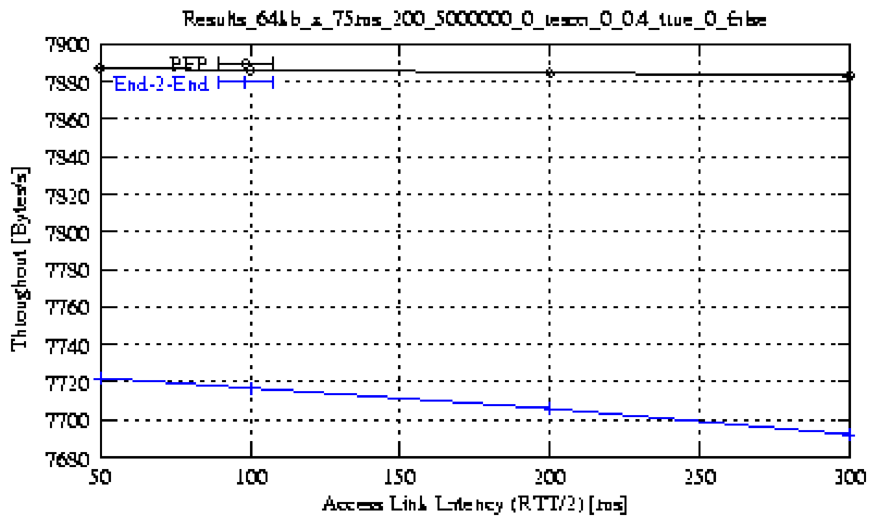


Simulation Results I

- 64 kbit/s; 0% packet loss



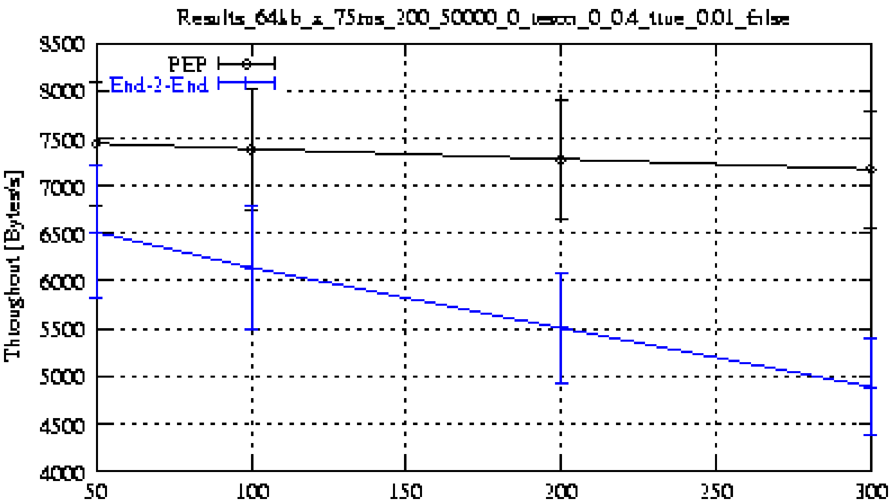


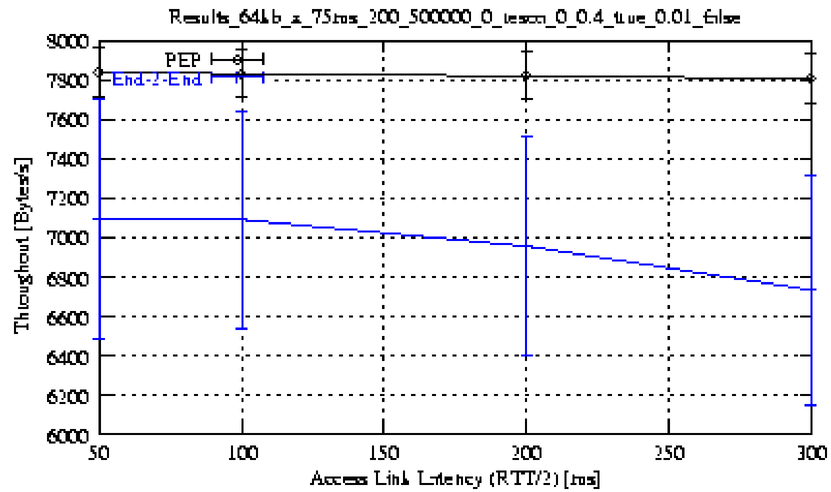


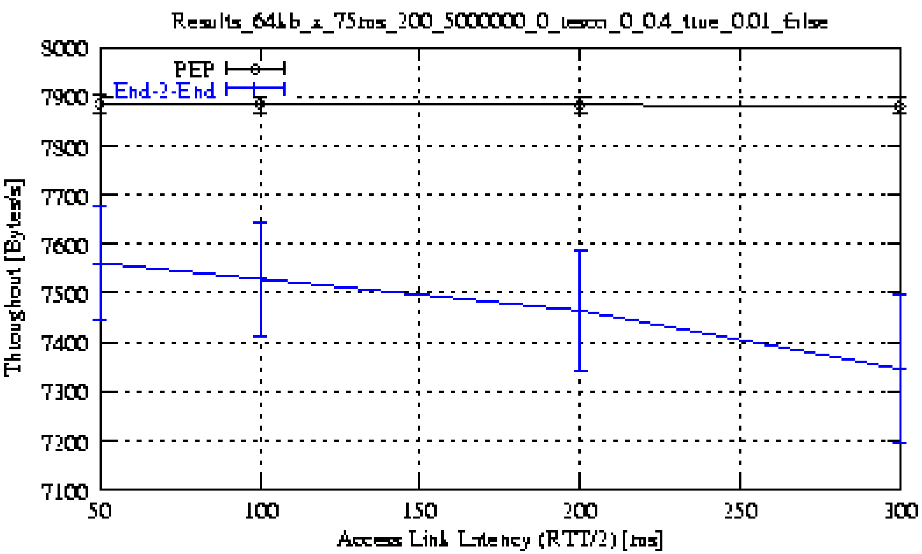
% im-provemen	50 ms	100 ms	200 ms	300ms
50000	12	18	30	44
500000	3	4	5	6
5000000	2	2	2	2

Simulation Results II

- 64 kbit/s; 1% packet loss







% im-provement	50 ms	100 ms	200 ms	300ms
50000	14	20	32	46
500000	10	10	12	15
5000000	4	4	5	7

Simulation Results III

- 384 kbit/s; 0 and 1% packet loss

% im-provement	50 ms	100 ms	200 ms	300ms
50000	51	86	156	224
500000	9	14	25	37
5000000	2	3	4	5

% im-provement	50 ms	100 ms	200 ms	300ms
50000	52	94	162	231
500000	24	43	86	130
5000000	19	39	91	153

Simulation Results – Summary

- ReSoA outperforms TCP in all cases
- Even though reliable link layer is used!
- Particularly important for small files
- Performance benefits increase with
  - Data rate in the wireless link layer protocol
  - Delay in the wireless link layer protocol
  - Error rate (congestion) in the Internet

Implementation

- Implemented for Linux 2.4.x as kernel modules
- IP address of server is used
  - A nicer, gentler NAT without application-level gateways
- Runtime environment for different LHPs (kernel module)
  - Registration of LHPs
  - Wrapper functions
- Example LHP based on IP (kernel module)
  - Second LHP running without IP under development.

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Current work on ReSoA

- Removing the single point of failure (ReSoA server)
- Using this concept to implement handover
- Studying these concepts in multi-hop wireless networks

Conclusions ReSoA

- Performance of pure TCP is not satisfying in wired/wireless networks
- Reliable link layer protocols are insufficient to cure these deficiencies
- ReSoA moves part of the socket functionality into the wired network
  - Custom-tailored link-layer protocols can be used
  - Beneficial for low-end terminals
- Performance can be considerably improved

Backup slides

Implementation of Connect Call

Implementation of `write()` call

- Write call is used to send data.
- Function returns when data was accepted by attached protocol (blocking bahvior)
- Application can set send buffer size.
  - Send buffer holds data which was not sent or not acknowledged yet
- Socket object decides when to block an application and when to pass data to TCP
- Write call in ReSoA
  - Handled locally by LSM
  - Send buffer management is done is distributed fashion

Implementation of `read()` call

- Read is used to read data from the socket receive buffer
- Function returns when enough data is available
- Application can set size of receive buffer
  - TCP‘s advertised window depends on receive buffer size
- Read in ReSoA
  - All data are passed to the end-system when received and not when application calls the read function.
  - Receive buffer on Remote Socket Server is updated when data was consumed by the application
  - Advertised window must not be opend before data was read

Linger option

- Close function is blocked until all data are acknowledged by peer TCP entity (or linger timer has expired)
  - Does not gurantee that all data are consumed by application
- Return of close call can be interpreted as all data have reached final destination
- In ReSoA this is not neccessarily true, since acks are sent by Remote Socket Server
- Solution: FIN segment is not acknowledged before all data were successfully send to the end-system

Addressing

- Addressing of Remote Socket Client and Remote Socket Server
  - Responsibility of LHP.
- Internet view on addressing
  - End-system can have its own globaly visible IP address
  - End-systems share a set of IP addresses

Analysing Capacity Improvements in Wireless Networks by Relaying

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Overview

- Group overview
- TCP in wireless networks (ReSoA)
- Capacity in ad-hoc networks
  - *Motivation and general idea*
  - Model description
  - Mathematical treatment
  - Results & Interpretation
  - Future work and Conclusions

Scenario

- Wireless local area networks (WLAN) increasingly used in many setups

- Important metrics
  - Total amount of traffic sustained by an AP
  - Number of terminals supported at minimal QoS
  - Fairness between terminals
  - Further possibilities: QoS guarantees, energy efficiency

Impediments

- What are impediments to maximization of these metrics?
  - To transmit with desired bandwidth, minimal signal quality is required
    - Signal quality: depends on received signal compared to noise and interference (SINR)
  - Need to match transmission power and modulation
    - “Faster” modulations need better signal
  - Noise is a given constant

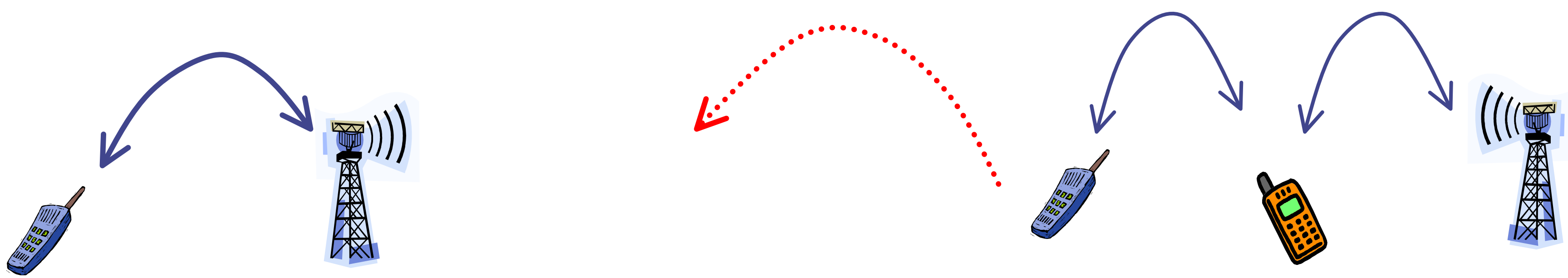
  - Possibility to reduce interference?

Reducing interference

- Interference: caused by other terminals transmitting with high transmission power
  - Usually terminals of other cells
- Lowering transmission power would reduce interference
- But: received signal strength is then too low to overcome distance to AP

Idea

- If distance is too large, communicate over shorter distance
  - Use intermediate nodes as relays
- Disadvantage: Relay nodes have to carry more traffic
- On the other hand: As all nodes use smaller transmission power, interference is reduced
  - Possible to use “faster” modulations to transport additional traffic?



Tradeoff relaying/lower transmission power

- Additional load on relaying „inner“ terminals
  - Intra-cell issue

vs.

- Lower interference from other terminals
  - Permitting to use faster modulations to handle additional load
  - Inter-cell issue
- Metric: total amount of traffic sustained by access point

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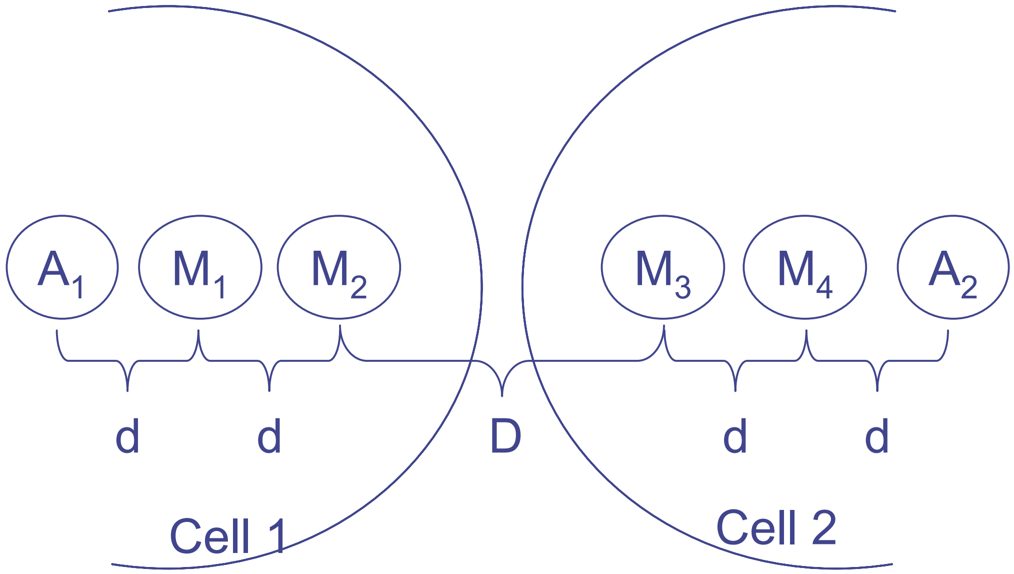
Model description

- Simple case, analytically tractable
- All terminals have infinite amount of data to send
- Goal: Provide as much total goodput as possible
  - Restriction: some minimum fairness between terminals



Model parameters

- As a case study, HiperLAN/2 is used
  - For mapping from SINR to packet error rate
  - Depends on chosen modulation, seven modulations exist
  - Consequence: TDMA!
- Parameters of the model
  - Path loss coefficient
  - Physical layout
- Controlled parameters (per terminal)
  - Transmission power
  - Modulation

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  - *Mathematical treatment*
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Analytical treatment

- Goal: Analytical expression for sum of the goodput of all terminals (= capacity)
  - For both direct and relaying scenario
  - Here only uplink case
  - For one particular scenario, in order to decide about potential of the technique

- Optimisation problem in power and modulation
  - Based on schedule which terminal is sending when
  - Subject to fairness constraints
  - Solved by discretizing transmission power and complete enumeration
  - Off-line analysis, details in the paper

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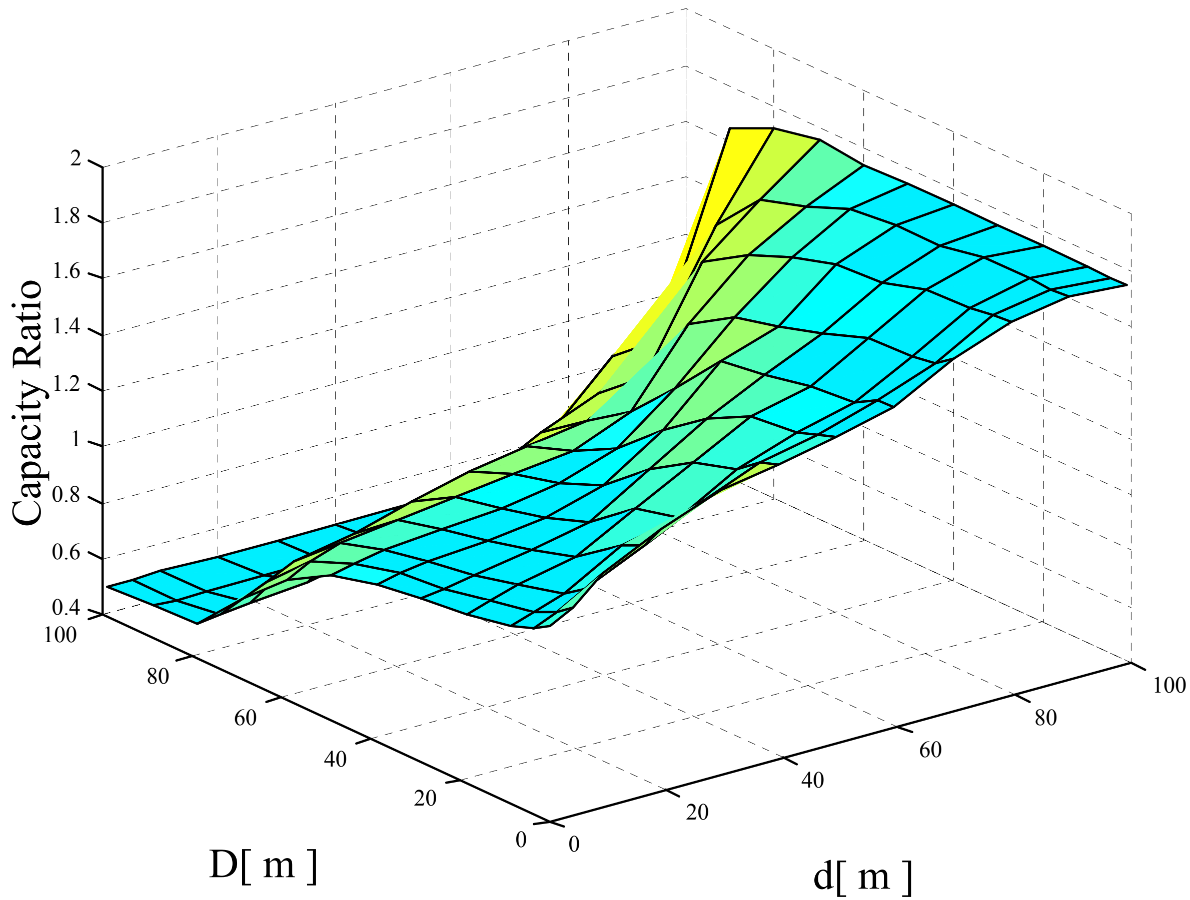
Results (α=3)


Capacity Ratio
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
100
80
60
40
20
0
D[m]
0
20
40
60
80
100
d[m]

Interpretation

- Relaying is good when:
  - Path loss coefficient is large (indoor environments)
  - Cells are large (terminals far away from access points), but close together
- Put the other way around:
  - Relaying allows to pack cells closer together
  - Need for spatial separation is reduced
  - Spatial reuse can be increased
- Particularly attractive for environments with lots of traffic (many cells)
  - E.g. exhibition halls, apartment/office buildings

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Related & Future work

- Lot‘s of work on relaying in general
  - As a routing problem to extend coverage
  - Relaying to improve capacity hotly debated

- Our current work
  - Extension to HiperLAN/2 to allow relaying – to be implemented
  - Simulator for HiperLAN/2 to investigate larger scenarios
  - Computation of schedule/route considered as a linear optimisation problem with fast heuristics
  - How to use on-line measurements to decide when to use relaying, which power, which modulation?

Conclusions

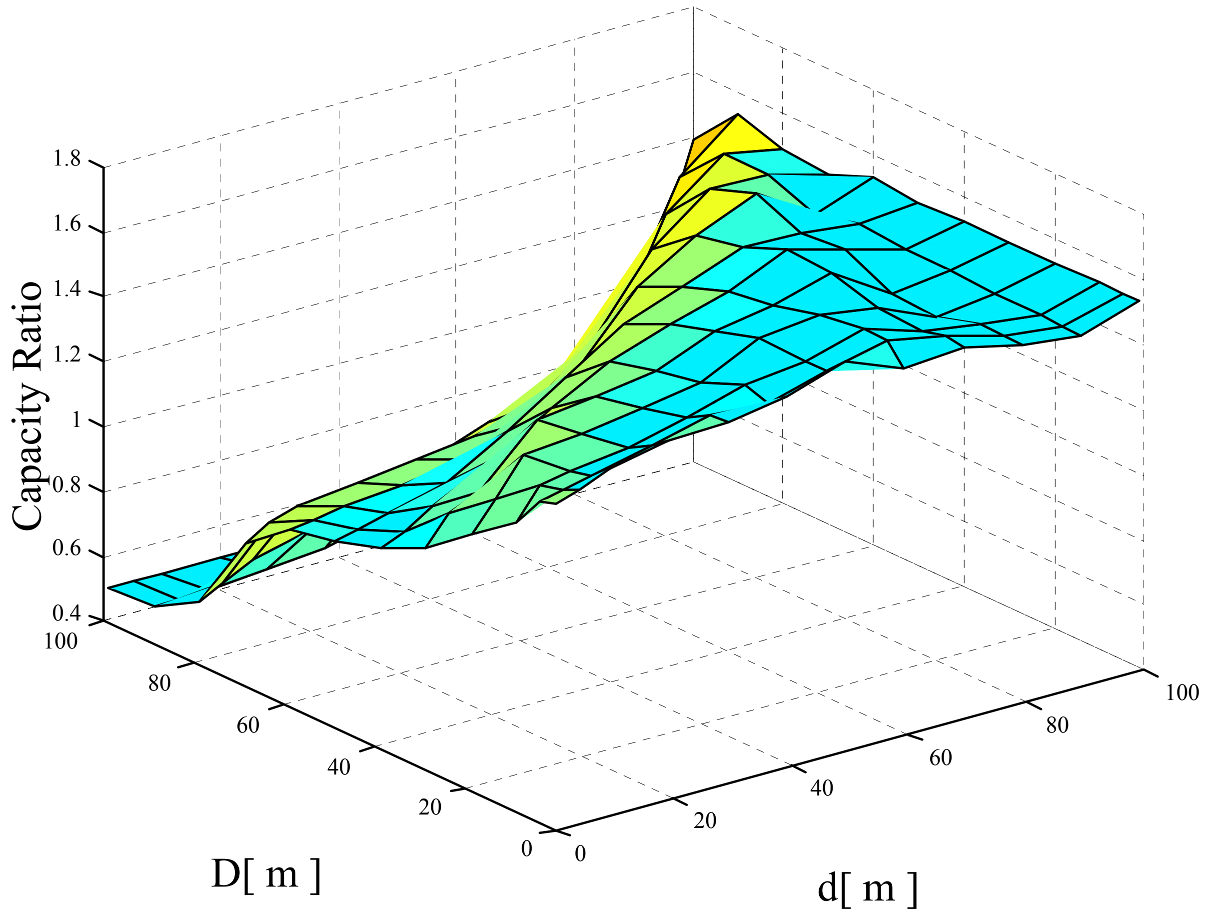
- Relaying can be beneficial to improve cell capacity
- Main contribution: Tradeoff between
  - Lower interference generated at the border of cells against
  - Higher traffic requirements in interior of cells
- Jointly optimising power and modulation is key technique

- Deciding when and how to use relaying based on actually on-line available channel measurements is still an open problem

Thank you!

More information:
http://www-tkn.ee.tu-berlin.de/

Results (α=2.5)



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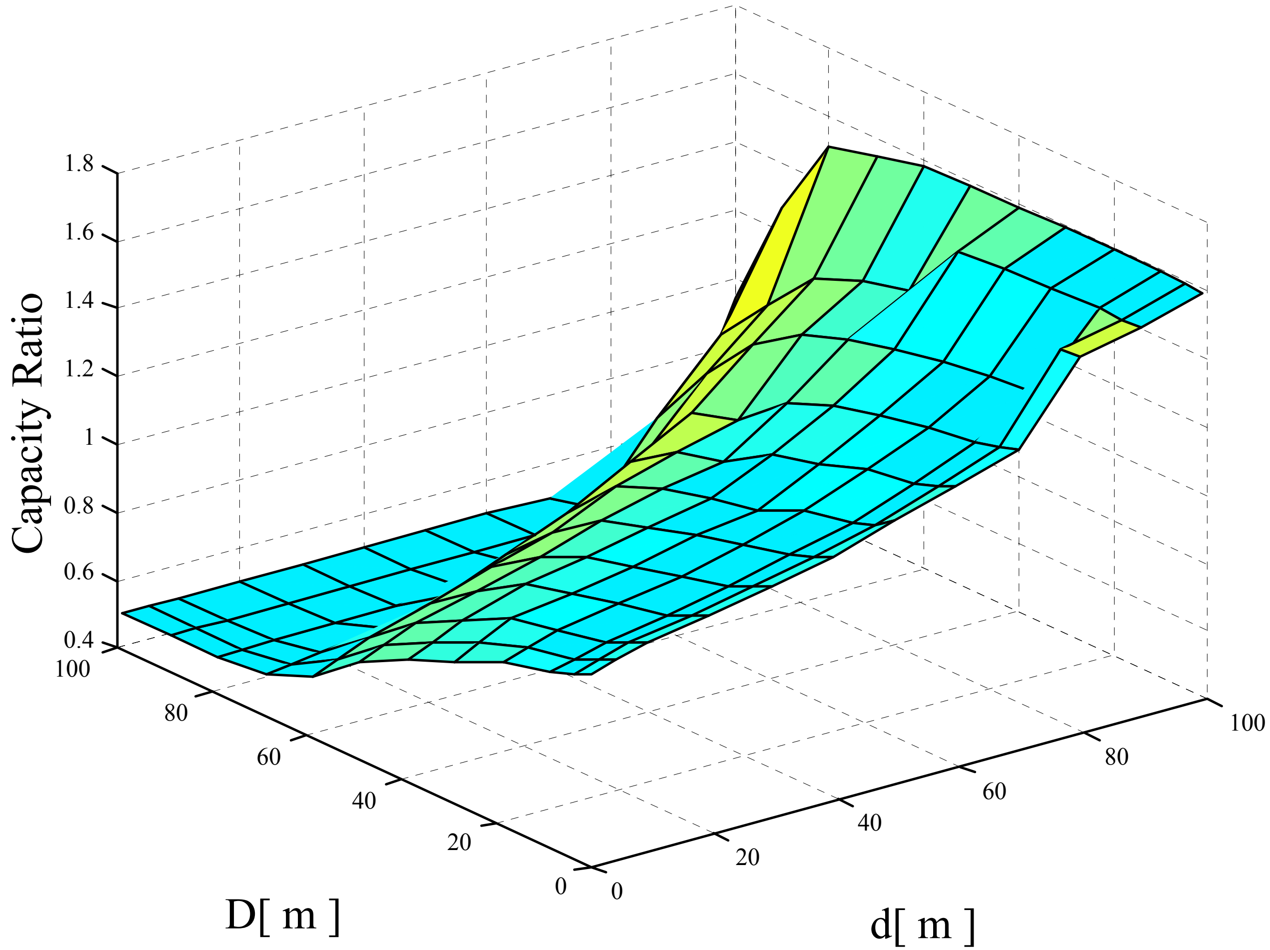
Results (α=4)



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