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Machine-to-Machine Applications meet Opportunistic Communications: Friends or Foes?

AOC Workshop 2013
June 4th, 2013
Madrid, Spain

the future

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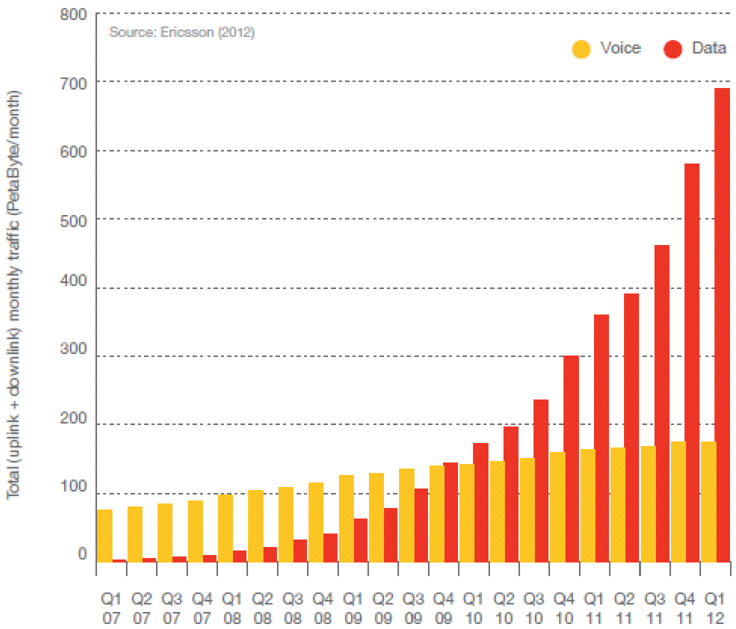
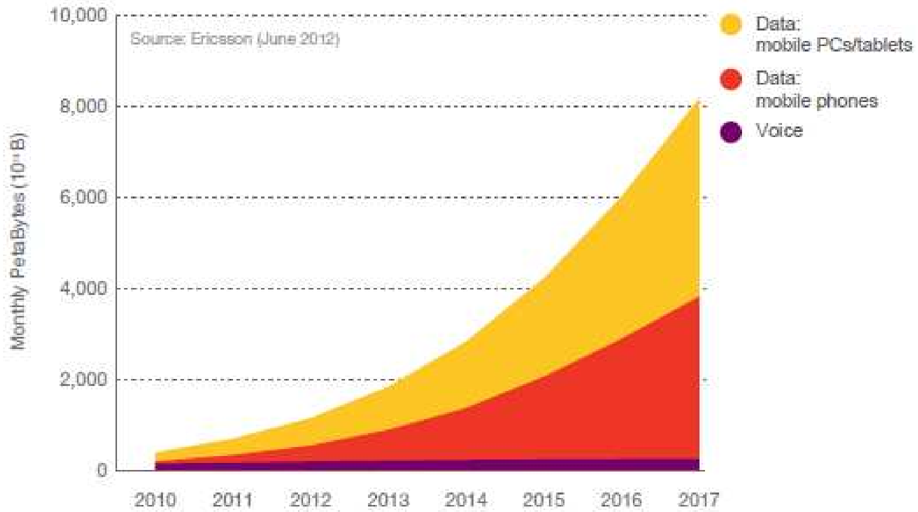
World Data Traffic: Status & Forecast

- The myth of exponential growth ?



Development 2007-2012



Predictions

By 2025 Ericsson expects a 1000-fold increase of data traffic!

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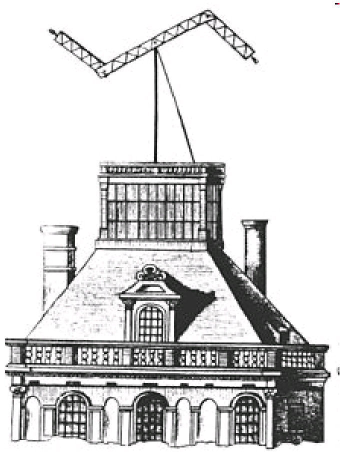
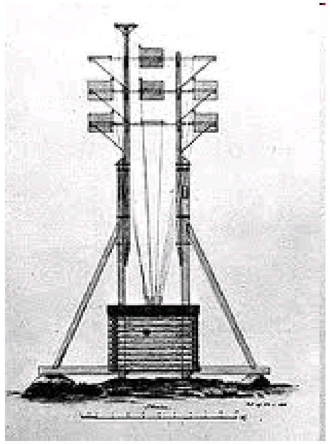
Purpose of Telecommunication Networks?

- Telecommunication <u>allows humans to benefit</u> from information although not being physically present.
  - Gives humans (potentially) an efficiency advantage

- One of the first telecommunication systems: Optical semaphore lines (~ 1800)



France



Sweden

Military use: Threats, orders

Financial use: Prices of bonds

➔ Operated by humans, used to exchange messages between humans

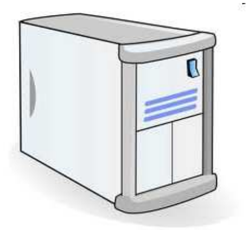
Direct Human Interaction

- Continuous evolution of systems that allowed humans to interact directly:
  - 1837/39: Electrical telegraph in US/England
  - 1856: Transatlantic telegraph (Victorian Internet)
  - 1870-1880: Electrical telephone
  - 1920s: Transition to electromechanical switching
  - 1950s: Publicly available transatlantic lines
  - 1960s/70s: Digital switching
  - 1970s/80s: Optical backbones
  - 1980s: Introduction of mobile phones

- All developments fueled by demand for telephony
- Early adopters: Military, Finance industry

Humans Interacting with Computers

- Computers provide two properties:
  - Storage of information
  - Processing (computation) of data



- In a networked context, this allows for novel applications with different efficiency advantages:
  - Automatically offer information at request
  - Manipulate data remotely

- Efficiency advantage made the Internet happen!
  - Early adopters: Military (ARPANET) and Financial Industry

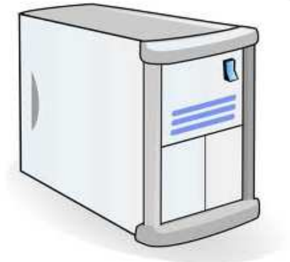
Today‵s Networks

<u>Humans interacting with humans</u>

Telephony, Messaging, Email, Social Web

<u>Humans interacting with computers</u>

WWW, P2P, Streaming, Apps



Increase in efficiency

Massive increase in devices and traffic

Always humans directly involved in information exchange!

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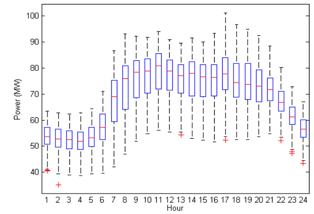
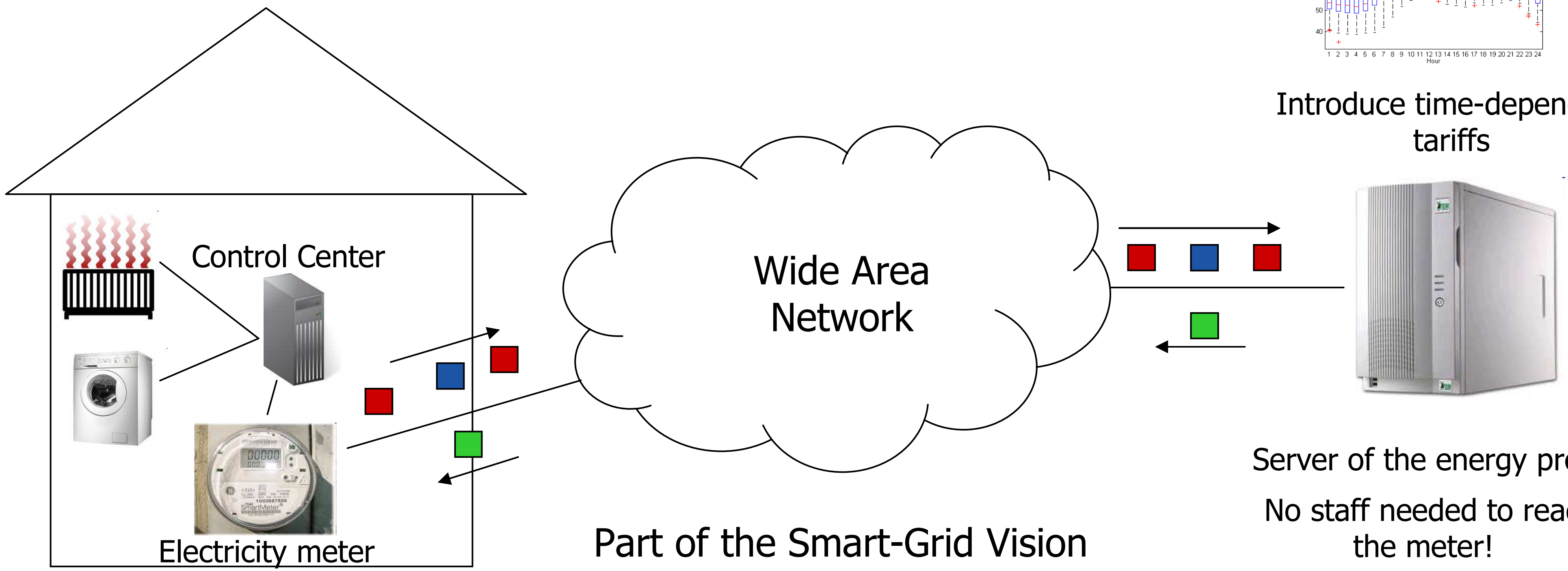
So What Comes Next?

- Use telecommunication networks for automation and monitoring tasks in various different scenarios.
  - Example: Electricity metering



Introduce time-dependent tariffs



Server of the energy provider

No staff needed to read the meter!

Part of the Smart-Grid Vision

Promises **significant efficiency advantage**!

Adjust power consumption of the house to current tariff!

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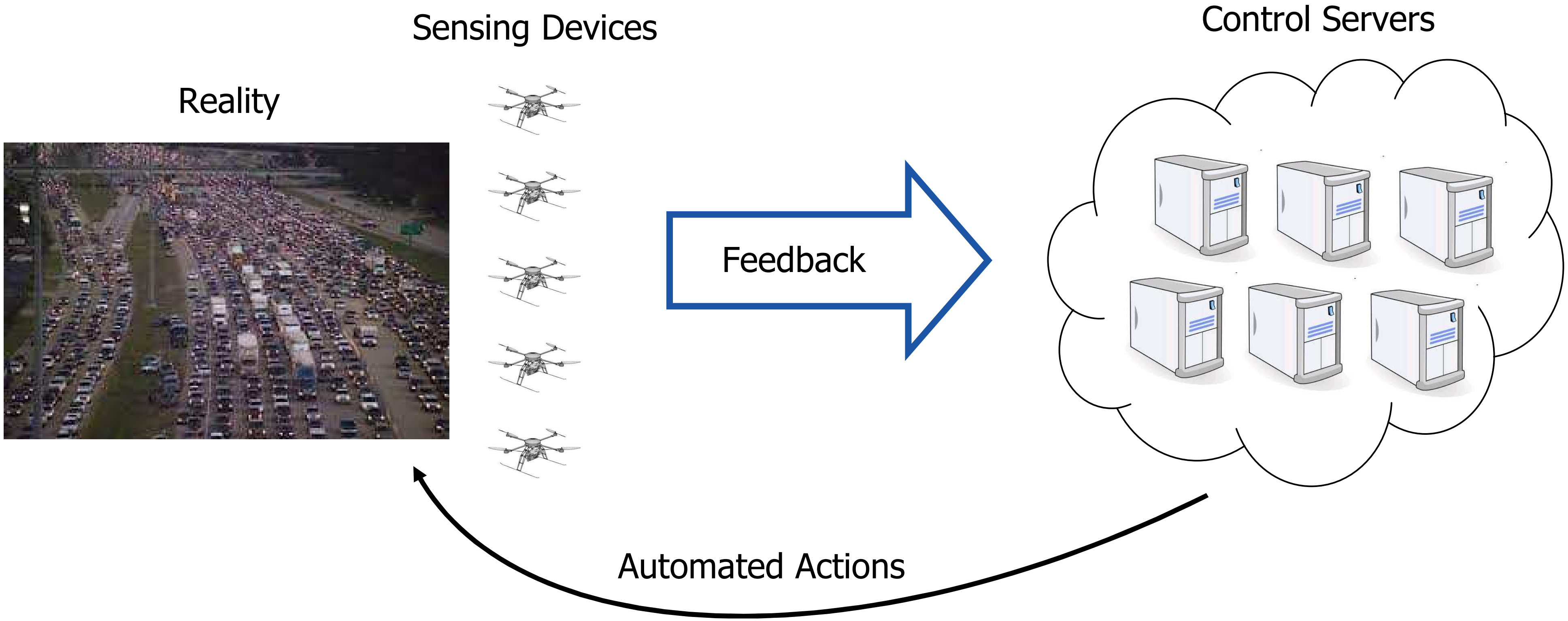
Third Fundamental Application Type

- No direct human involvement anymore, instead computers constantly exchanging status and control information ➔ Control-Service Applications !



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Control-Service Applications: Impact?

- We already see various scenarios:
  - Smart Grid
  - Vehicular Cloud
  - Smart Cities
- Essentially, these applications will be deployed wherever there is an efficiency advantage
- Skeptical ? There is already something in place …
  - High frequency trading at stock exchanges: Fully automated trading of shares according to algorithms
    - Reaction delay in the range of micro- and milliseconds
    - Accounts for about 50% of all trades at NYSE
  - Finance sector used to be an early adopter …

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Consequences for Networks

- Dramatic change ahead ?
- At least, a set of different & novel requirements:
  - Reliability and timeliness become important
  - Small packet sizes
  - Large number of devices
    - Ericsson predicts 50 billion devices by 2025
  - Most connections involve wireless ➔ cellular / other ?

- Leads to very interesting research problems !
  - Reliability/latency guarantees possible in such networks?
  - Protocol engineering for low latency/high reliability ?
  - Point of computation for applications ?
  - Network architectures ?
  - Privacy / Security ?

Control meets Opportunistic Comm.

- Opportunistic communication seems an odd candidate:
  - Delay-intolerant instead of delay tolerant required
  - Tight control of topology required
  - No explicit reliability guarantees possible

- However, opportunistic communication also provides some interesting features:
  - Energy-efficient
  - Low spectrum requirements

- Can control-type applications benefit from opportunistic communications?
  - For which type of control applications interesting?
  - Under which conditions ?

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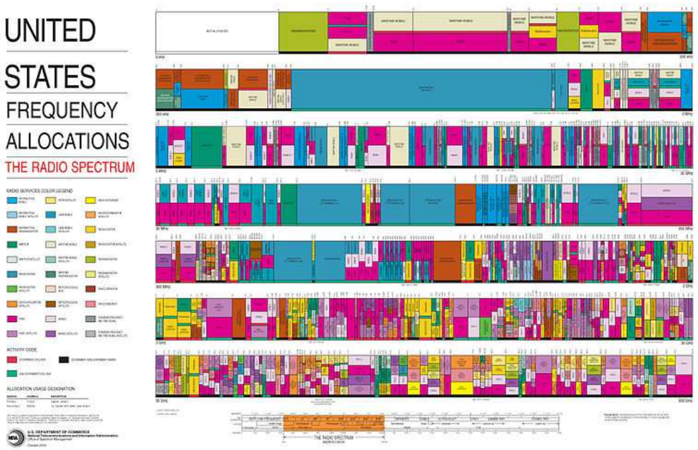
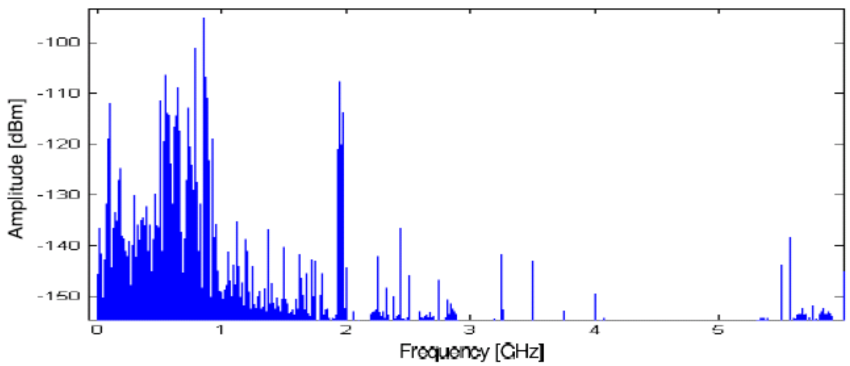
Example: Opportunistic Spectrum Access

- The well established story …

Spectrum Allocation



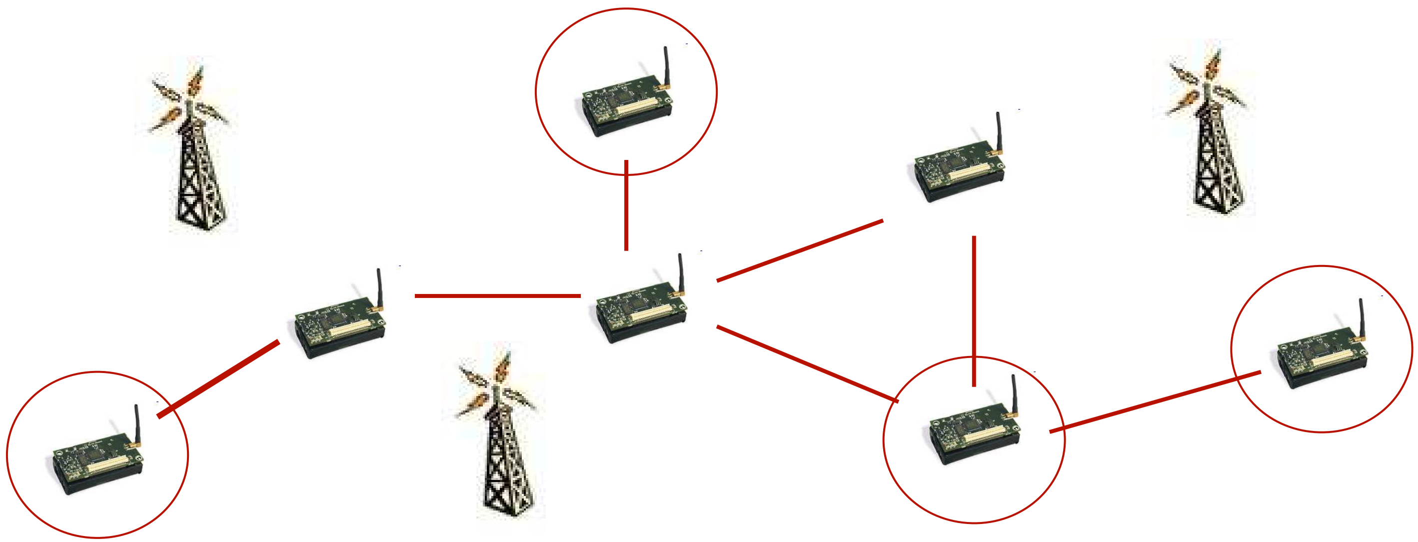
Spectrum Usage



- Opportunistic spectrum access allows spectrum reuse:
  - Overcome discrepancy between allocation and usage
  - Secondaries have to vacate the spectrum if primary appears

Control-Type Applications and Opportunistic Spectrum Access

- Assume a mix of primary and secondary systems
  - Control-applications run over secondary devices

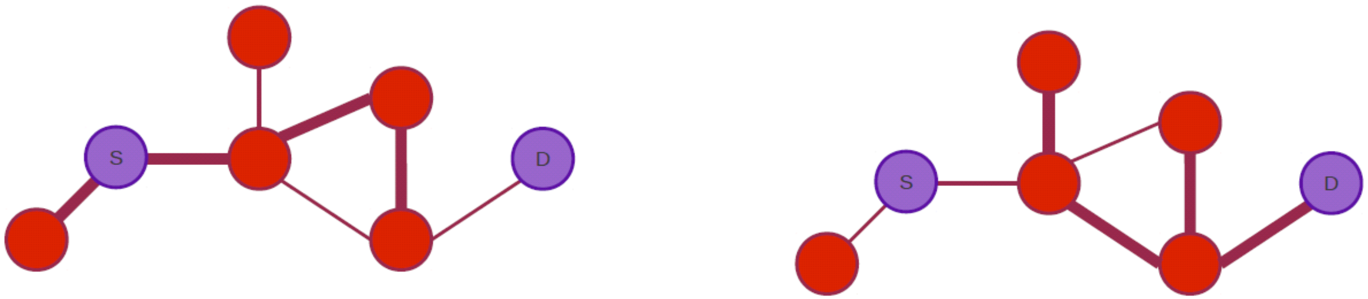


- Can we support control applications at all in such a network? Under which conditions is this possible?

Joint work with S. Tenbusch, C. Löding and F. Radmacher from RWTH Aachen

Control-Type Applications and Opportunistic Spectrum Access

- Assume time-slotted behavior, fixed nodes, constant traffic (source & destination) & varying link capacities



Identify conditions for stability, throughput and delay **guarantees**

Automated checking of such conditions

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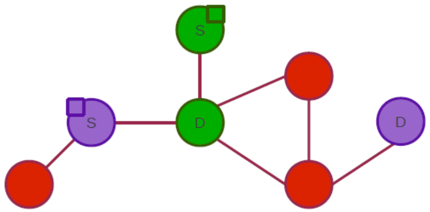
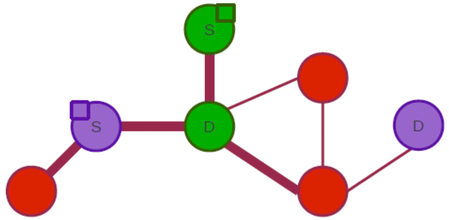
Analysis Approach: 2-Player Infinite Games

- Well established theory for controller design
- Turn-based approach with demand and routing agent
  - Demand agent action:

Packet Generation

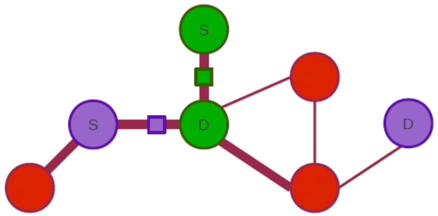


Channel Blocking

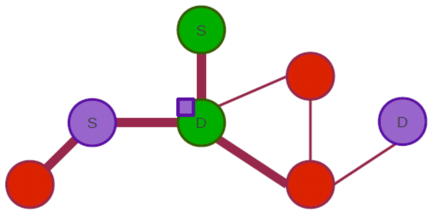


  - Routing agent action:

Packet Routing



Packet Removal



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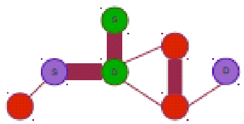
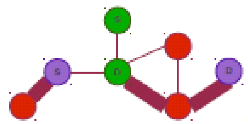
Game Definition

- Formally, define a game and a winning condition
  ➔ Check if there exists a winning strategy

- Game definition:
  - Topology
  - Traffic pattern
  - Set of primary blocking patterns:

$\mathcal{B} = \{$  ,  $, \ldots \}$

- Winning condition:
  - Stability: Number of packets stays bounded

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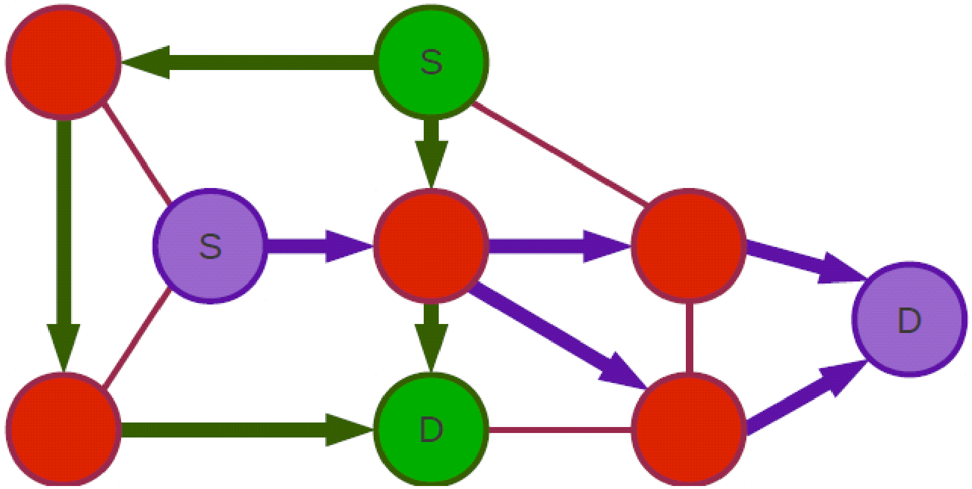
Winning Condition & Strategy

Theorem

Routing Agent has a winning strategy $\Leftrightarrow$ For all capacities $B \in \mathcal{B}$ a suitable **Multi Commodity Flow** (MCF) exists.



Strategy:
Route along corresponding MCF while B is active; ignore rest

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Delay Bound?

- We can even find a delay bound, requires:
  - Some additional capacity in the flows per B pattern
  - Minimum capacity on the links which is periodically available

Delay bound under **stricter** condition:

Theorem

If for each $B \in \mathcal{B}$ an MCF with excess throughput $\varepsilon > 0$ exists and the minimal capacity on each node is $c_{\min} > 0$:
Routing Agent has a winning strategy with some delay bound D.

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So what ?

- Compared to related work:
  - We do not rely on backpressure routing
  - We analyze a worst-case scenario
  - We provide *checkable* conditions for stability and delay:

Automatic check if Routing Agent can win
(QoS Guarantee)

For each $B \in \mathcal{B}$, check if suitable MCF exists.

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Checking QoS Conditions

- Problem: # of *B* patterns can be very large
  - Restrict to some max. utilization
    - i.e 80% , 90 % …

  - Allows to develop an algorithm which handles complexity

Start with capacity N on all nodes and call BACKTRACK($O_{\max}$)
BACKTRACK(o) does the following:

1. Calculate MCF with maximum throughput X
2. If $X < 1$ return current assignment
3. If $X \geq o + 1$ return NULL
4. Normalize MCF to throughput 1
5. For all involved nodes v:
   Reduce capacity on v by y s.t. MCF becomes invalid
   If BACKTRACK($o - y$) not NULL return BACKTRACK($o - y$)
   Restore capacity on v
6. Return NULL

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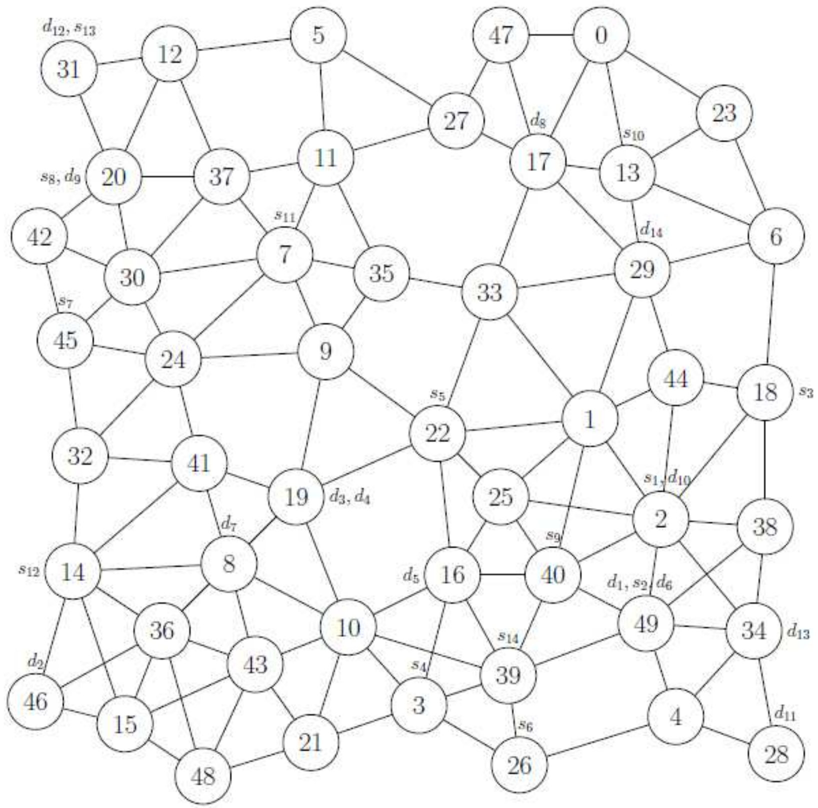
Example Evaluation

- Secondaries: $V = 50$
- Primaries: $P = 50$
- Channels: $N = 3$
- min. Channels: $c_{\text{min}} = 1$
- Traffic: $m = 8, 10, 12, 14$

O_{max}	$\lvert\mathcal{B}\rvert$
1	51
2	1.326
3	23.376
4	313.701
5	3.412.461
6	31.298.361
7	248.635.761
8	1.744.483.611
9	10.970.926.711
10	62.561.143.641



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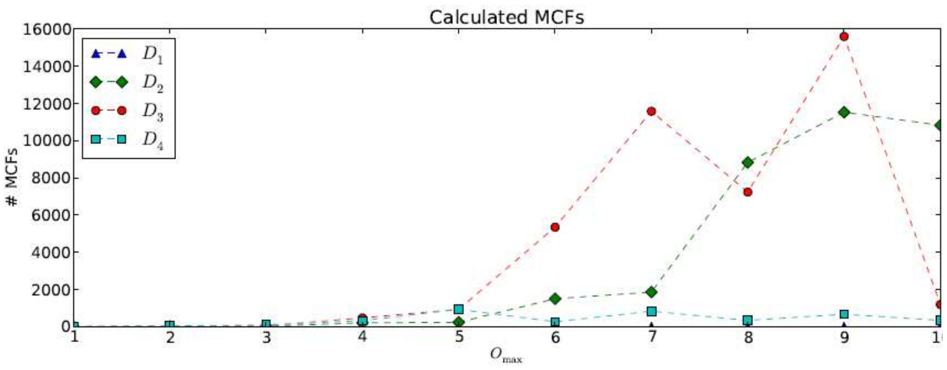
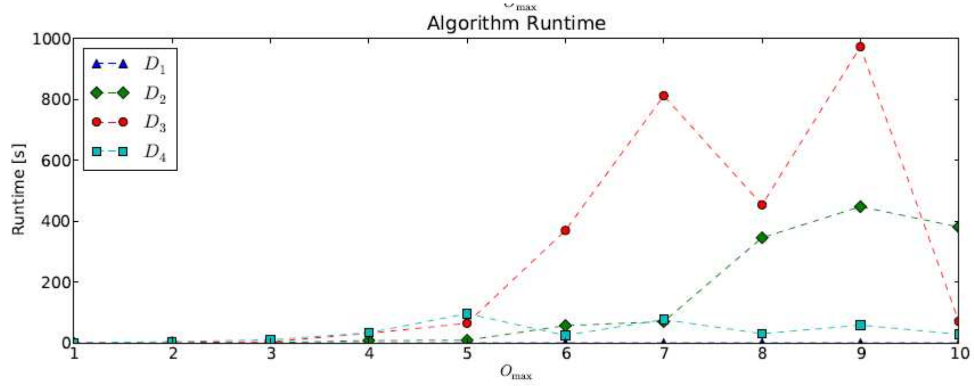
Example Evaluation





		O_{max}									
	m	1	2	3	4	5	6	7	8	9	10
D_1	8	●	●	●	●	●	●	●	●	●	●
D_2	10	●	●	●	●	●	●	●	●	●	○
D_3	12	●	●	●	●	●	●	●	○	○	○
D_4	14	●	●	●	○	○	○	○	○	○	○

● : Routing Agent wins

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Conclusions

- Raise of control applications in networks ?
  - Some believe: Massive impact
  - I believe: Lots of very interesting research problems
- Can opportunistic communications contribute ?
  - Depends on application requirements and resource availability in the network
  - Stability and delay bounds for opportunistic spectrum access as an example
    - Can check beforehand if requirements can be met!
    - OSA can be used