Energy Efficient Cooperative Communications

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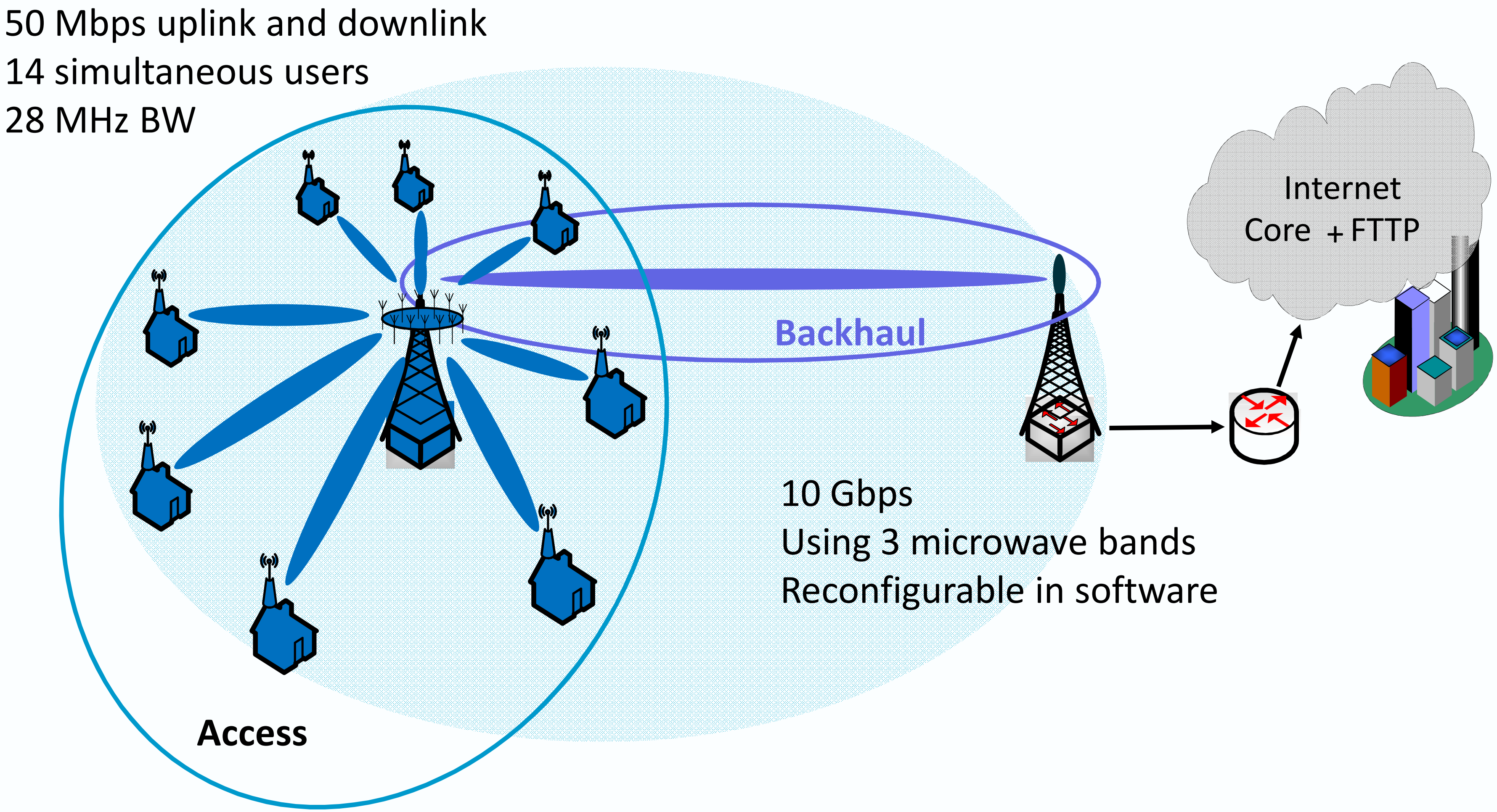
20th November 2013

With contributions from: Vijay Sivaraman, Ren Liu, Craig Russell, Maged Elkashlan & Phil Yeoh

Rural and Remote Broadband Communications



STAGE 2 : Ngara access demonstrations

Marsfield, Sydney December 2011

Wireless Sensor Networks

Light, Temp

Water Quality: pH, Redox, Temp, Conductivity

Soil Moisture

Motion: GPS, Accel,Gyro, Magnetome

Strain Gauges

DSP: Audio, Video

In the Field: Example CSIRO Deployments

Wireless Localisation System

System developed with features:

- High accuracy localisation
- Low cost hardware
- Provides high rate data communications
- No cabling required
- Operates in severe multipath

Wireless Localization Trials

Contributors to Energy Footprint

Datacenters

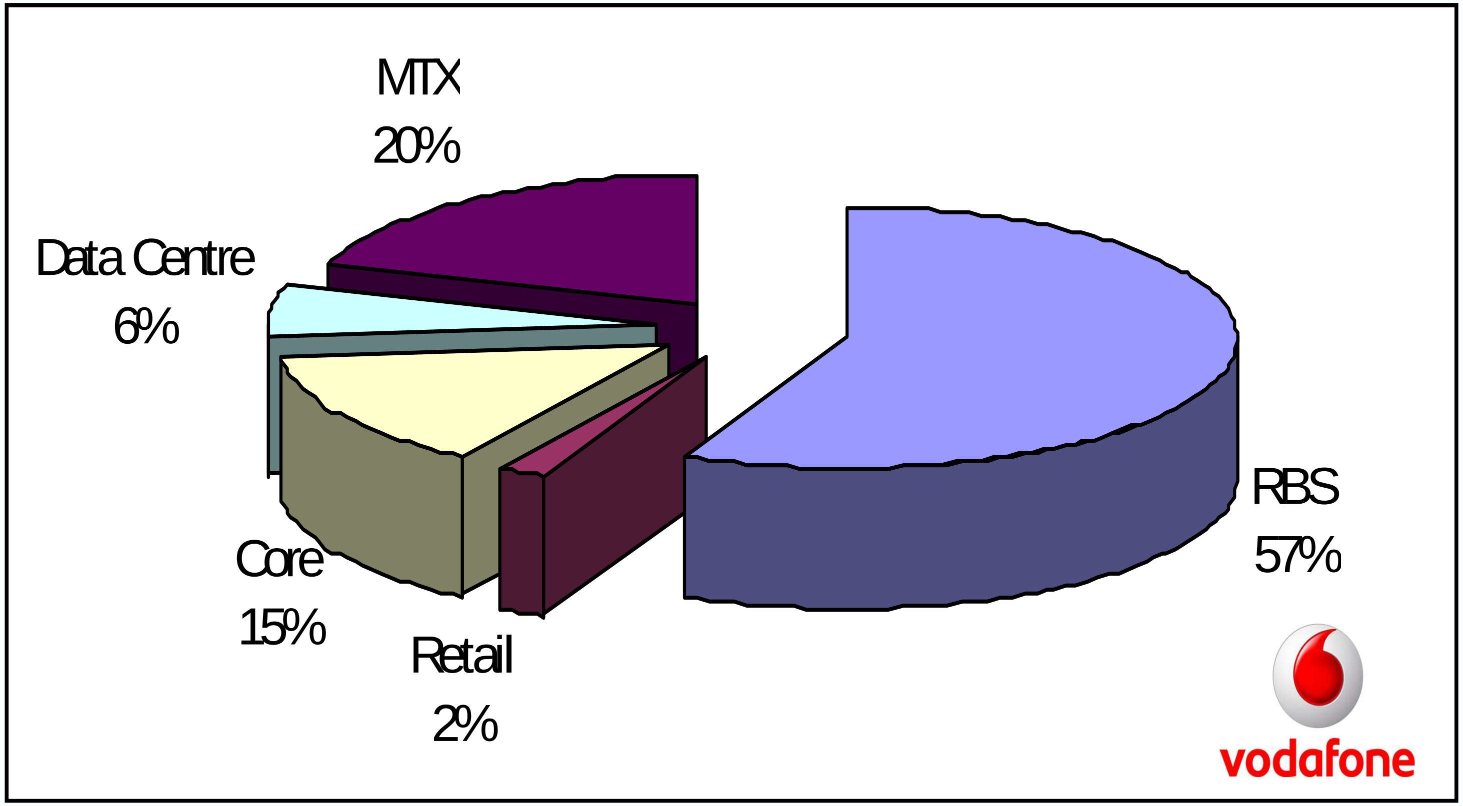
Backbone

?

Access network

PCs & peripherals

A view from Vodafone



- For the operator, 57% of electricity use is in radio access

Energy consumption of Telcos

Telecom Italia
2009 Sustainability Report

2.1 TWh

france telecom

3.7 TWh

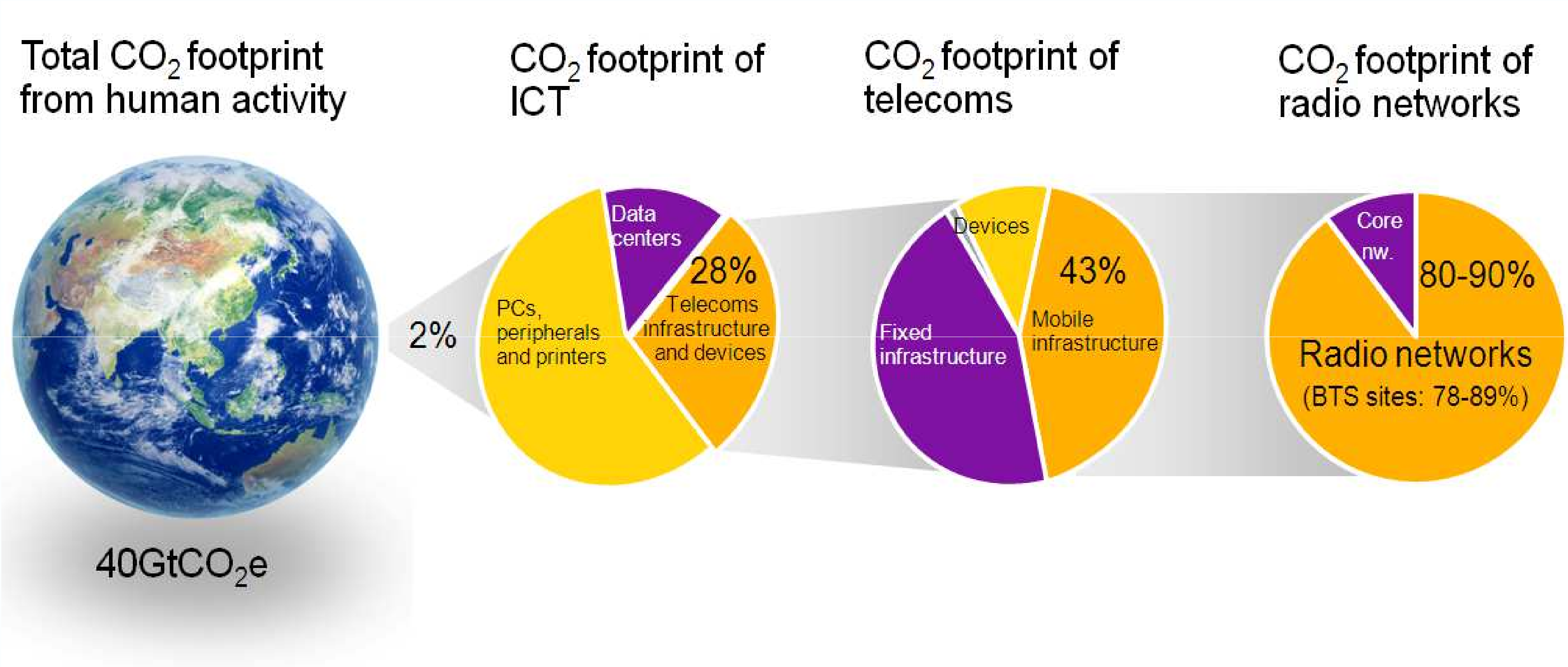
Annual Corporate Responsibility Report
Telefónica

4.5 TWh

verizon
Corporate Responsibility

9.9 TWh

ICT Carbon Footprint
A view from Nokia Siemens Networks



Sources : SMART2020 Report (The Climate group 2008) and Nokia Siemens Networks

A view from Alcatel-Lucent

2020 ICT CARBON FOOTPRINT

820m tons CO_2

360m tons CO_2

260m tons CO_2

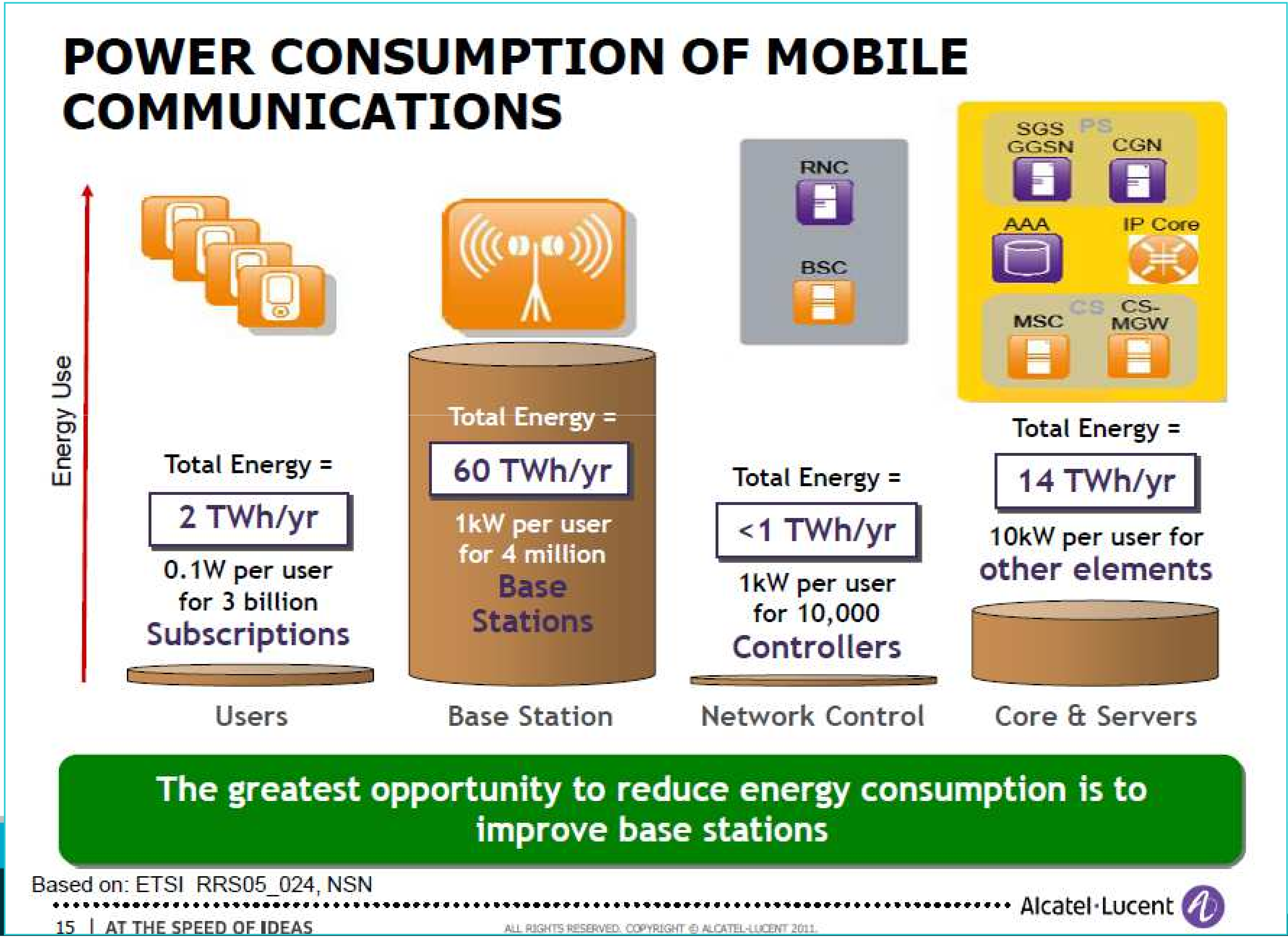
Total emissions: 1.43bn tonnes CO_2 equivalent

The Climate Group, GeSI report "Smart 2020", 2008

- 2007 Worldwide ICT carbon footprint: 2% = 830 m tons CO_2
- Comparable to the global aviation industry
- Expected to grow to 4% by 2020

Alcatel·Lucent

More from Alcatel-Lucent



Outline

- Energy in WLAN Access
- Basic sleep modes
- Cooperation in Wireless Networks
- Cooperative Sleep Modes in WLAN
- Machine to Machine communications
- Energy Efficient Ethernet
- Software Defined Networking

Motivations for exploring energy efficient WLAN

- Power consumption of BS (P_{BS}) and AP (P_{AP}):

$$P_{BS}(typically:1000W) >> P_{AP}(typically:10W)$$

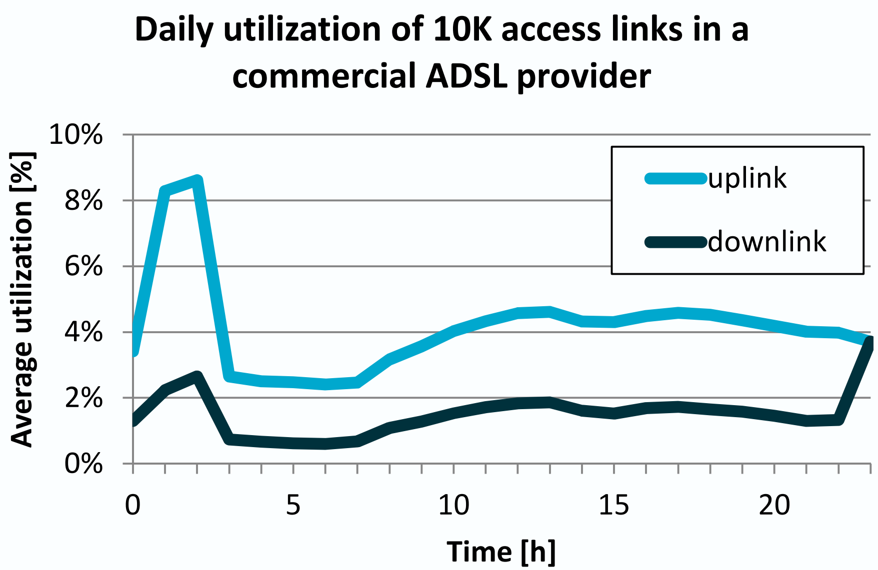
However, WLAN is widely deployed in most homes

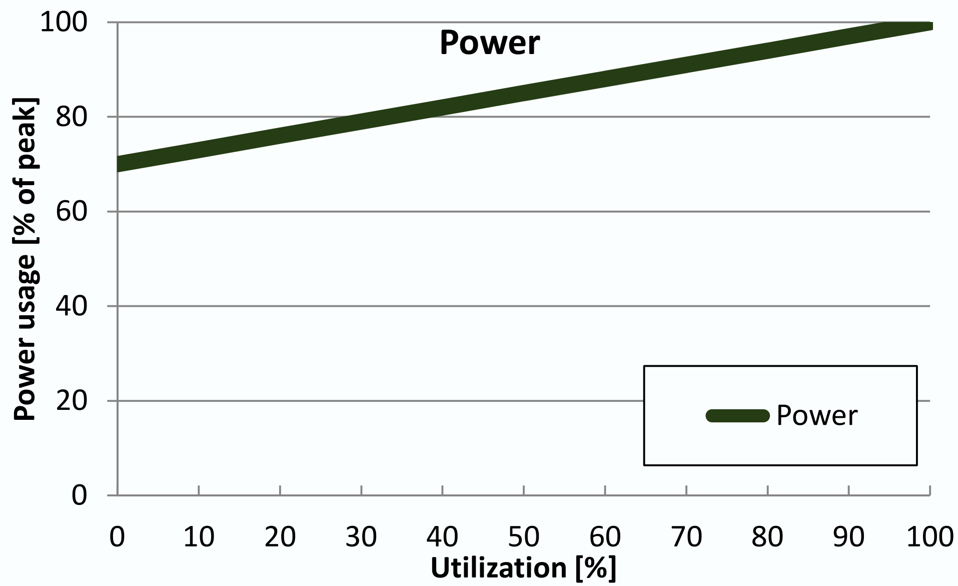
- Typically, in a given area, the number of BS(N_{BS}) and AP(N_{AP}):

$$100N_{BS} << N_{AP}$$

WiFi Access

- Huge number of devices
  - 2 orders of magnitude more gateways than DSLAMs
  - 3 orders of magnitude more gateways than metro devices
  - 4 orders of magnitude more gateways than backbone devices
- High per bit energy consumption
  - At full load, access devices consume 2-3 orders of magnitude higher energy-per-bit than metro/backbone
- Utilization < 10%





WLAN Access Point - Carbon Footprint

One household AP (Home AP)

- 10 W, 24x7 active: produces 48 kg of CO_2 annually

Australian NBN proposes to connect 10 million premises

- Combined power consumption: 100 Mega Watts
- Equivalent to 500 Tonne of CO_2 annually

Overall: WLAN power consumption is not to be neglected.

V. Sivaraman, C. Russell, I.B. Collings and A. Radford,
"Architecting a National Optical Open-Access Network: The Australian Challenge",
IEEE Network: The Magazine of Global Internetworking, Vol. 26, No. 4, pp. 4-10, July 2012.

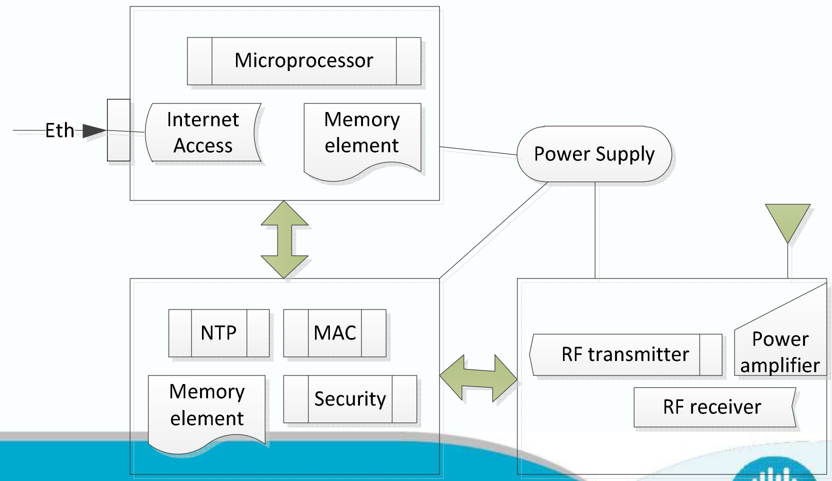
Importance of Implementation

Energy Efficient Hardware Design

- RF frontend: radio transceiver
- FPGA: modulation, MAC, Security
- Microprocessor: device control, Internet access

AP Sleep modes

- Microsleep: turn off RF frontend
  implement 802.11 intra-frame power saving
- Deepsleep: turn off FPGA and RF
  implement cooperative long sleep



Cross Layer Considerations

- Models for circuit energy consumption highly variable
- Transmit energy can be minimized by waiting for good channels
- Circuit energy consumption increases with on-cycle duration
  - Introduces a delay versus energy tradeoff for each bit
- High-level modulation costs transmit energy but saves circuit energy (shorter transmission time)
- High order precoding techniques not necessarily energy-efficient
- Short distance transmissions require TD optimization
- Coding costs circuit energy but saves transmit energy
- Sleep modes save energy but complicate networking

Standard Sleep Modes

- For long sleep duration, network access delay increases
- Long sleep could prevent some applications starting and/or operating
  - some applications (e.g. Skype, Messenger, Sensors) generate low rate keep-alive or report stream (a data packet every 1~100ms), which result in an AP not busy, but also not inactive – cannot go to sleep.
- If sleeping duration is small, boot up time dominates
  - low sleep efficiency

Cooperative Sleeping

- AP deployment density is high
- AP is on low or no traffic most of the time (80~90%)

Idea

- Share AP among neighbouring households
- Low rate and start up applications have network access through a shared “AP "On Duty"
- Most APs can have long sleep – improving sleeping efficiency

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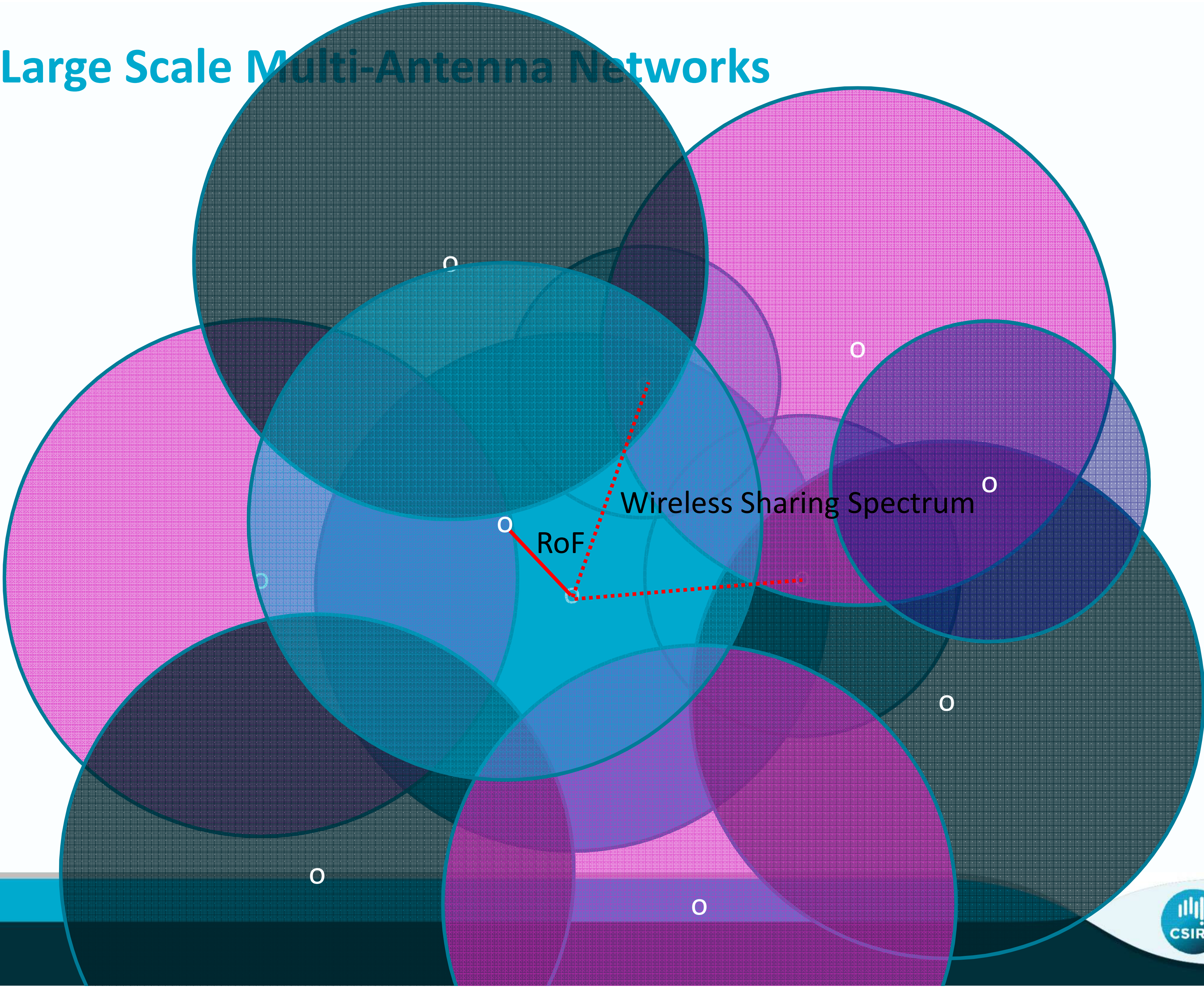
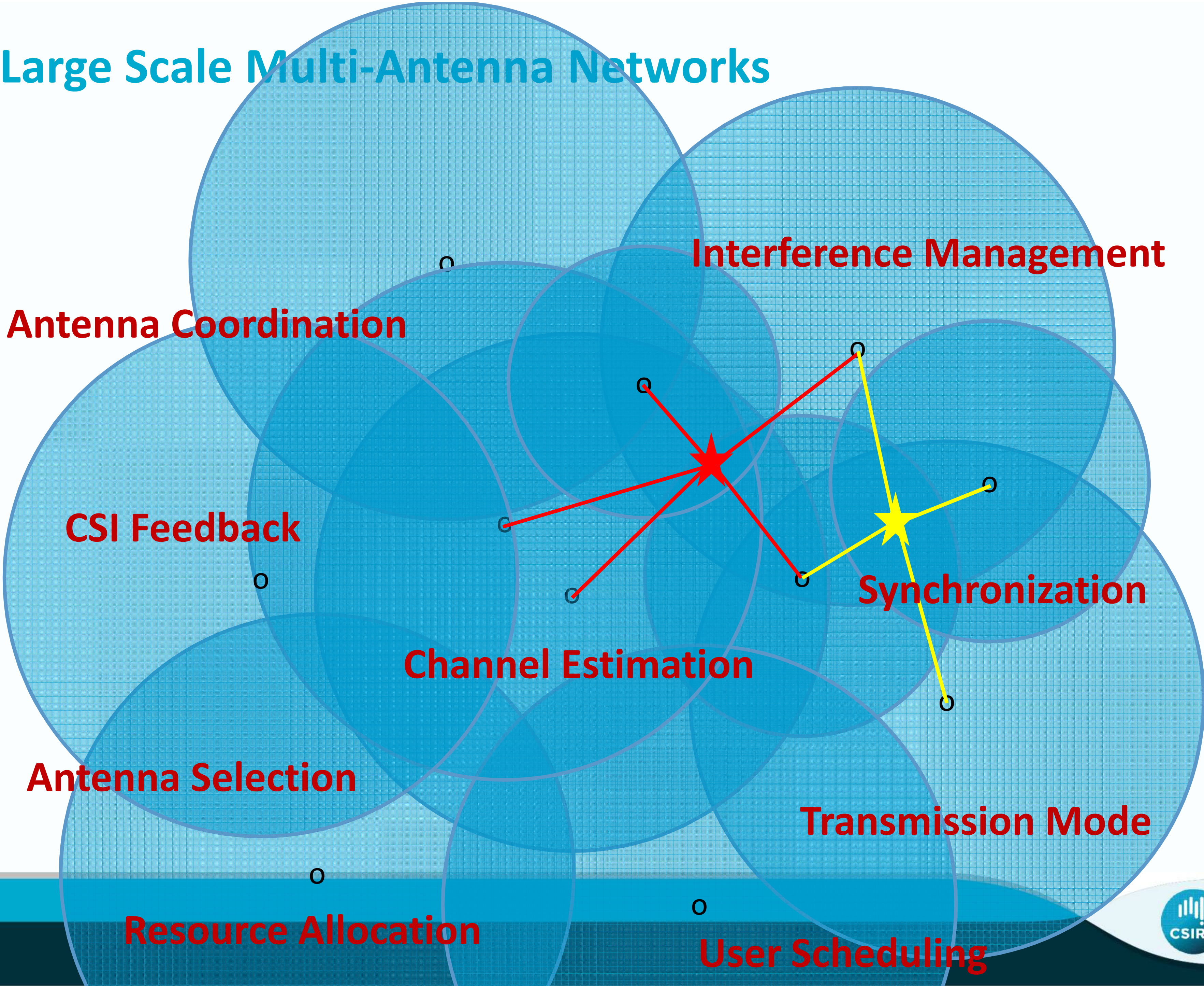
Large Scale Multi-Antenna Networks



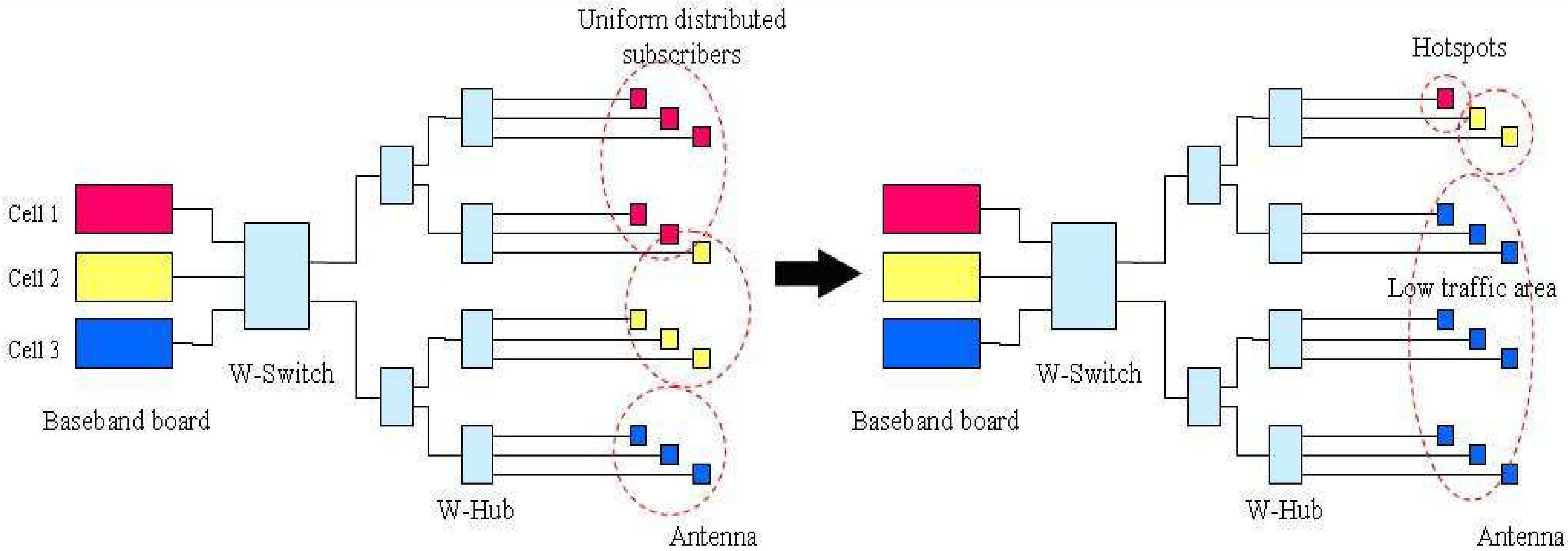
Large Scale Multi-Antenna Networks



Adaptive Wireless Access Networks

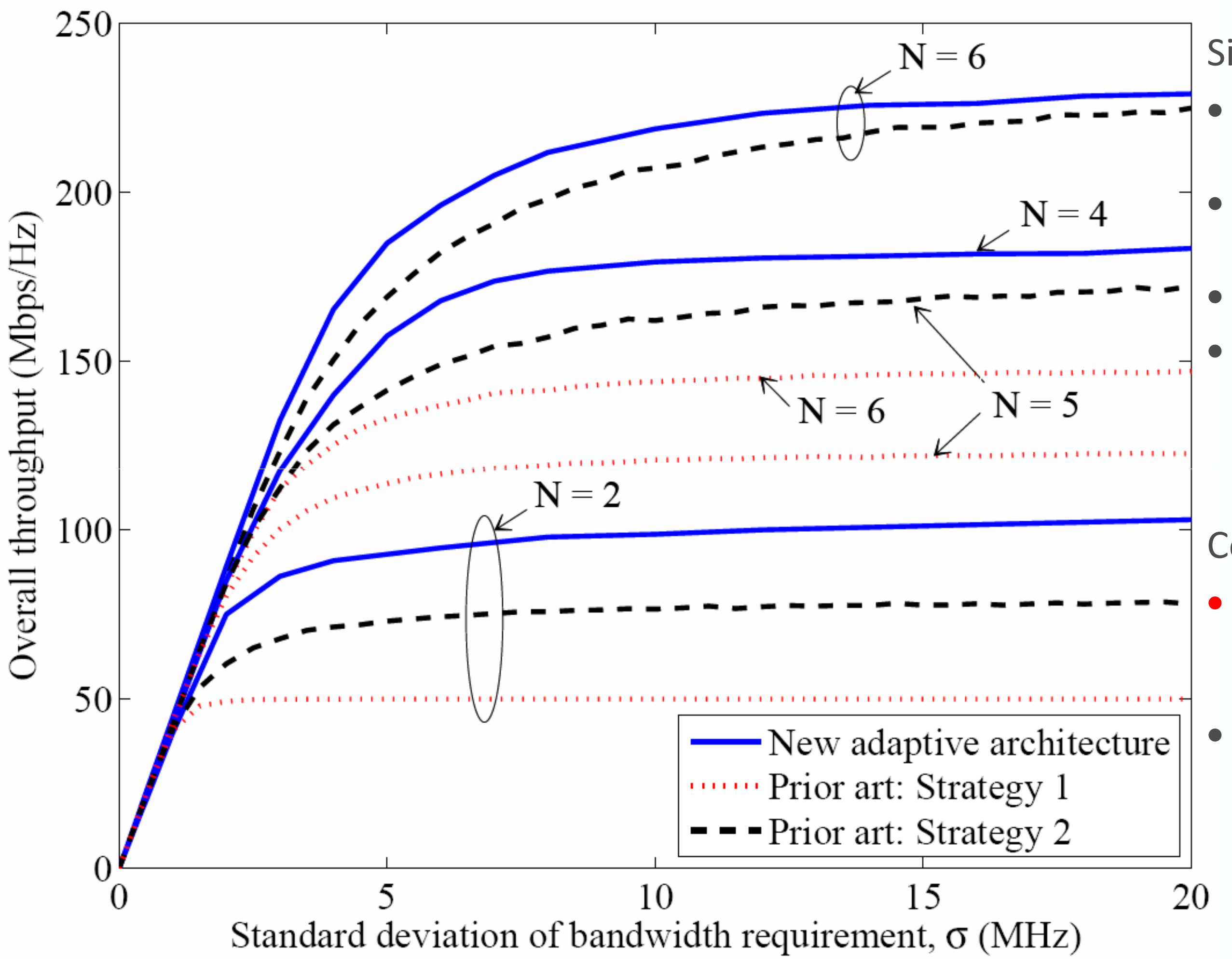
Reconfigurable topology

Adaptive spectrum allocation



W. Ni and I.B. Collings, "Indoor Wireless Networks of the Future: Adaptive Network Architecture", IEEE Communications Magazine, Vol. 50, No. 3, pp. 130-137, March 2012.

Performance of the New Adaptive Architecture



Simulation setup

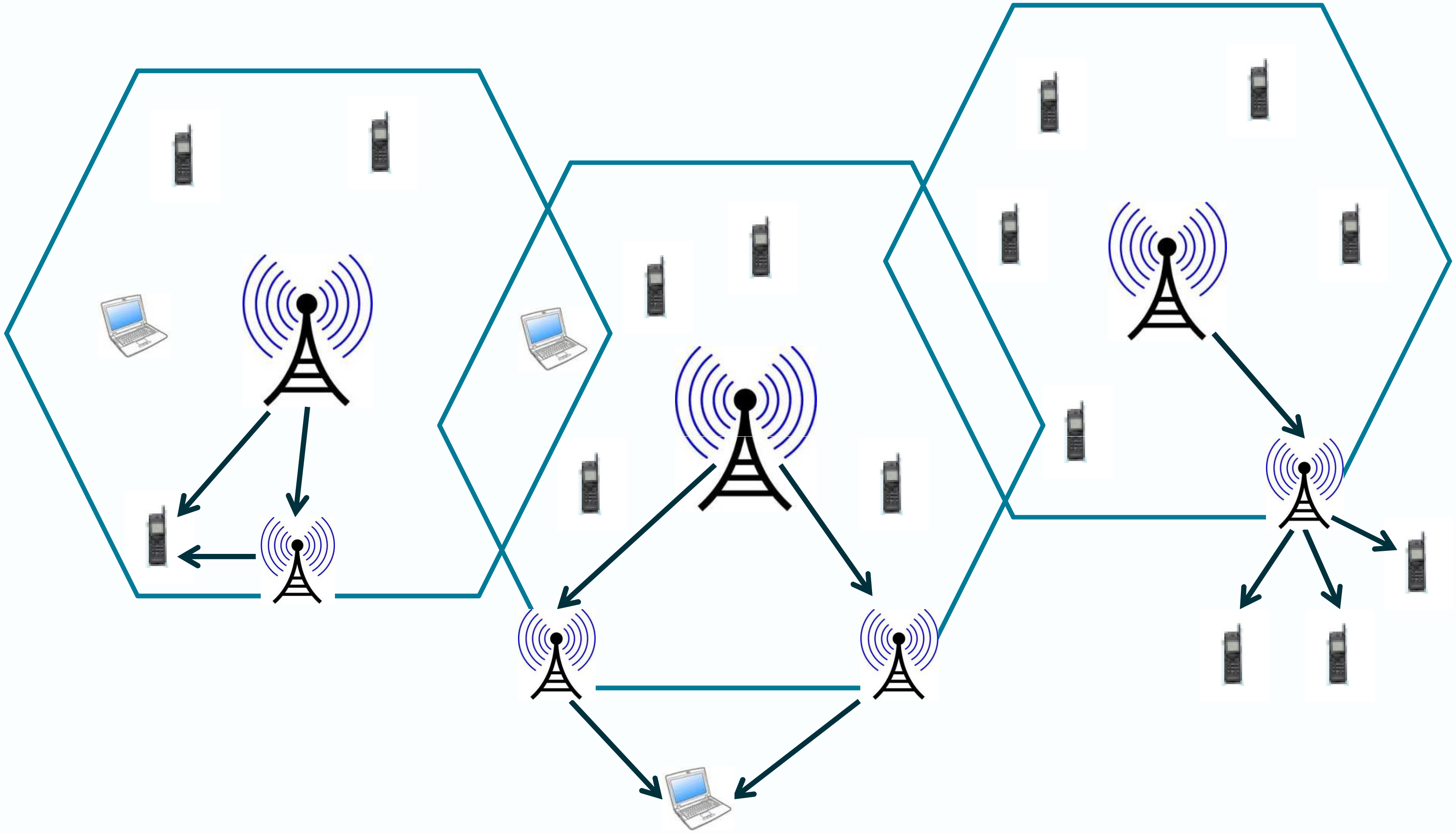
- A 6-floor 18-antenna indoor wireless network
- The number of BSEs is from 2, 4, 5 and 6
- Network bandwidth: 20 MHz
- Independent and identical distribution (IID) of traffic demands

Conclusion

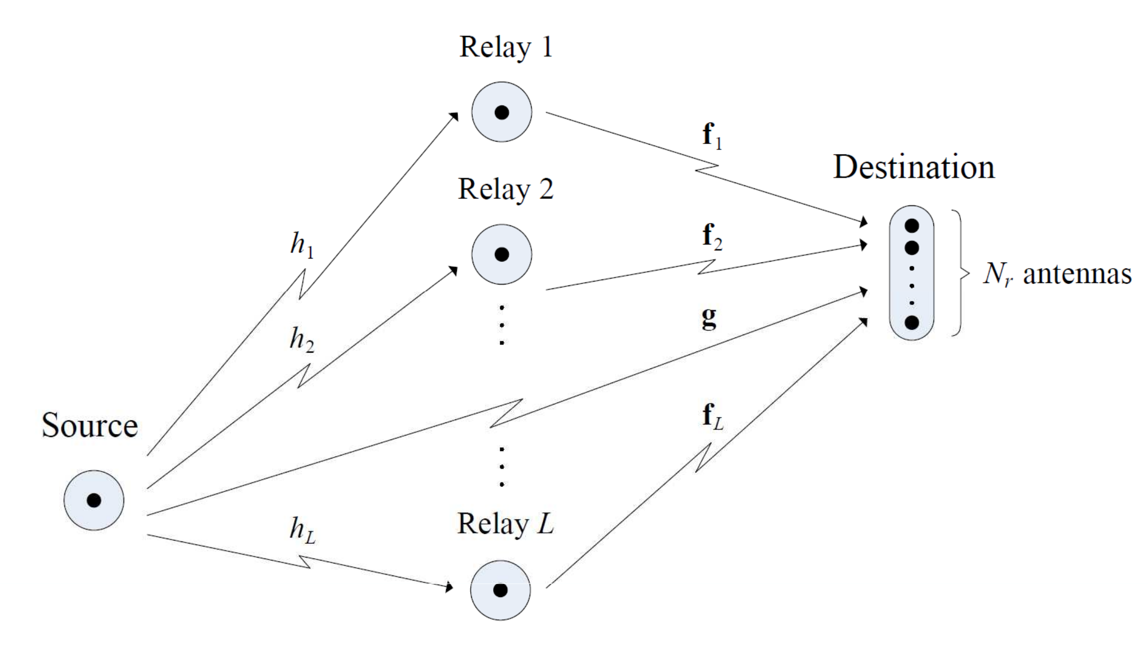
- New architecture with 4 BSEs outperforms existing approaches with 5 BSEs
- CAPEX saving is 20% on BSEs

indicates how significantly traffic demands (bandwidth requirements) change.

Distributed Wireless Networks



Cooperation vs Non-Cooperation



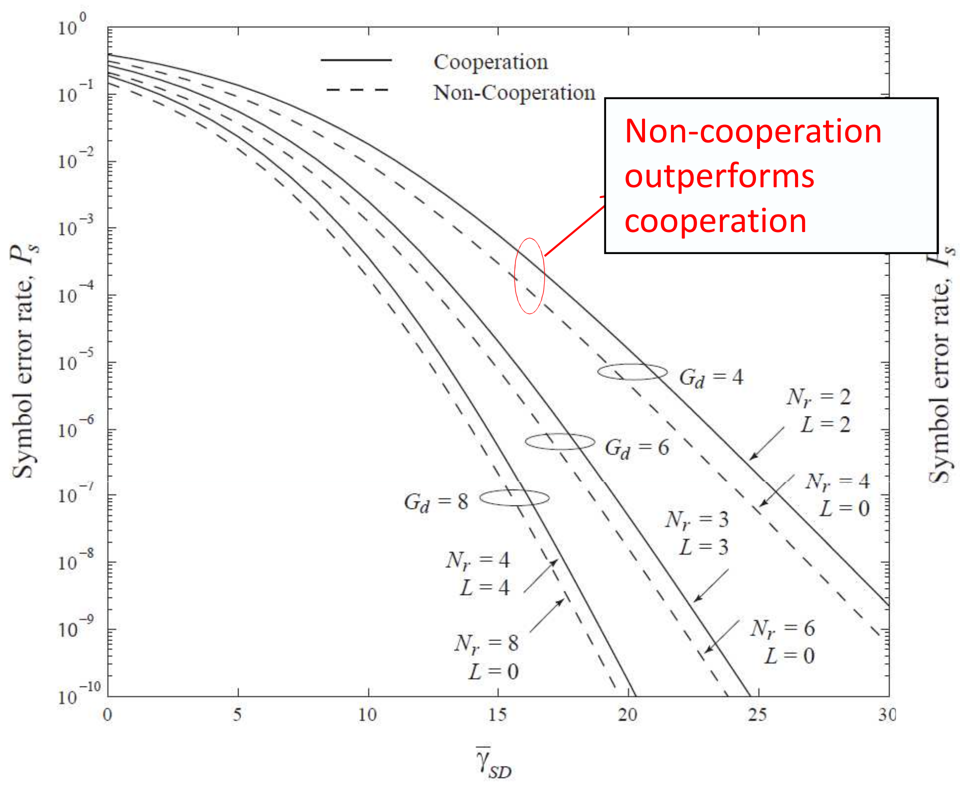
When do relays improve performance?

Cooperation: All the relays transmit and all the antennas at the destination combines the signal with MRC.

Non-cooperation: The relays are switched off. The source transmits directly to the destination which combines using MRC.

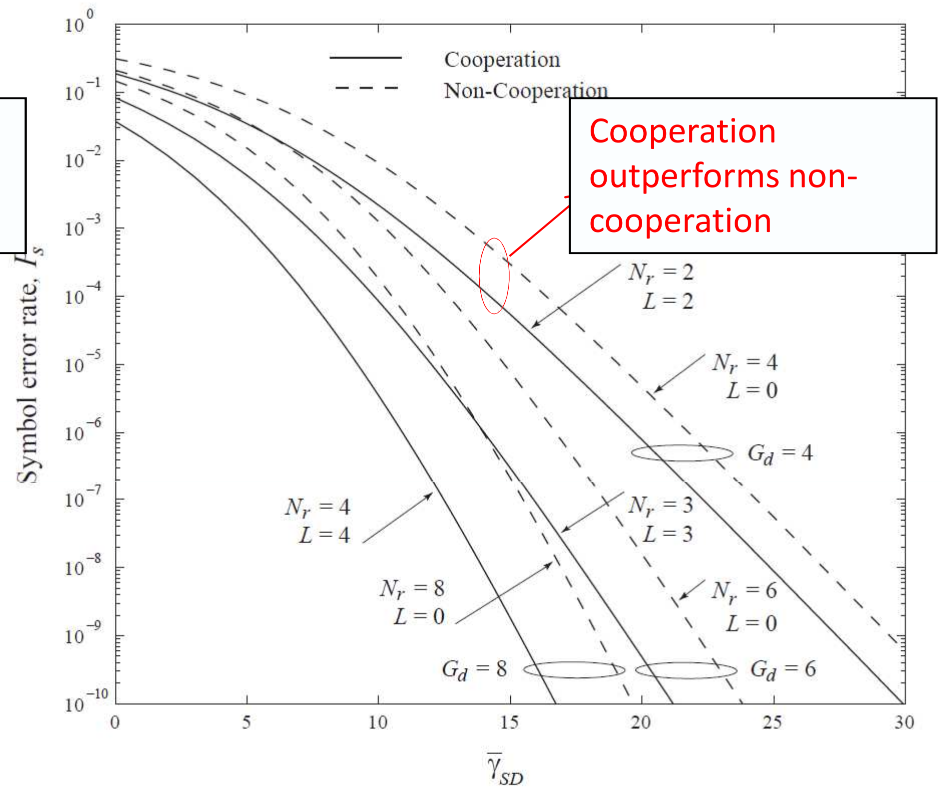
Cooperation vs Non-Cooperation

Strong Direct Link Scenario



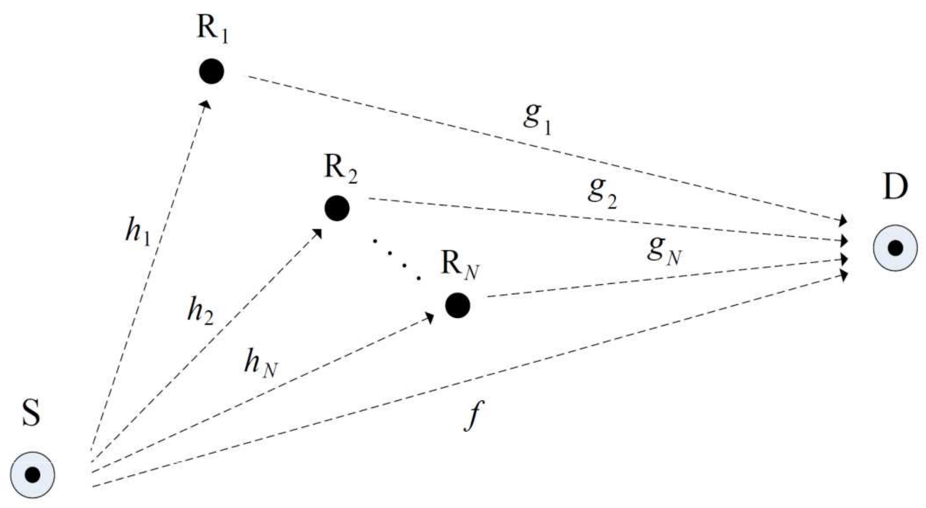
To achieve a desired diversity order it is better to design a multi-antenna receiver than design a relay system.

Weak Direct Link Scenario



It is better to design a relay system, assuming you have the extra bandwidth/timeslots.

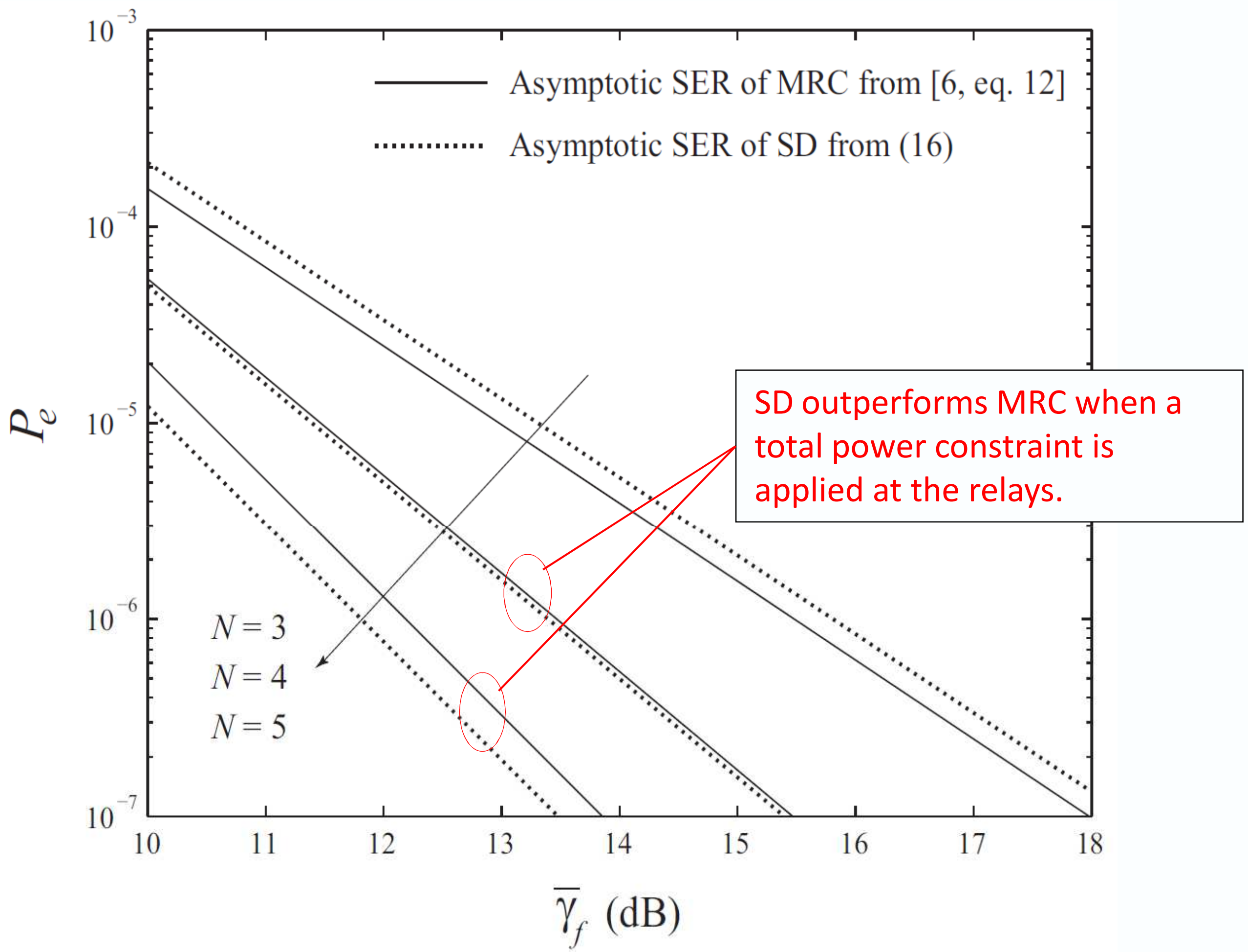
Selection Diversity vs All-Participate in Cooperative Networks



- Core concept: A wireless mesh network in which only the strongest link amongst the N+1 links is selected for transmission.

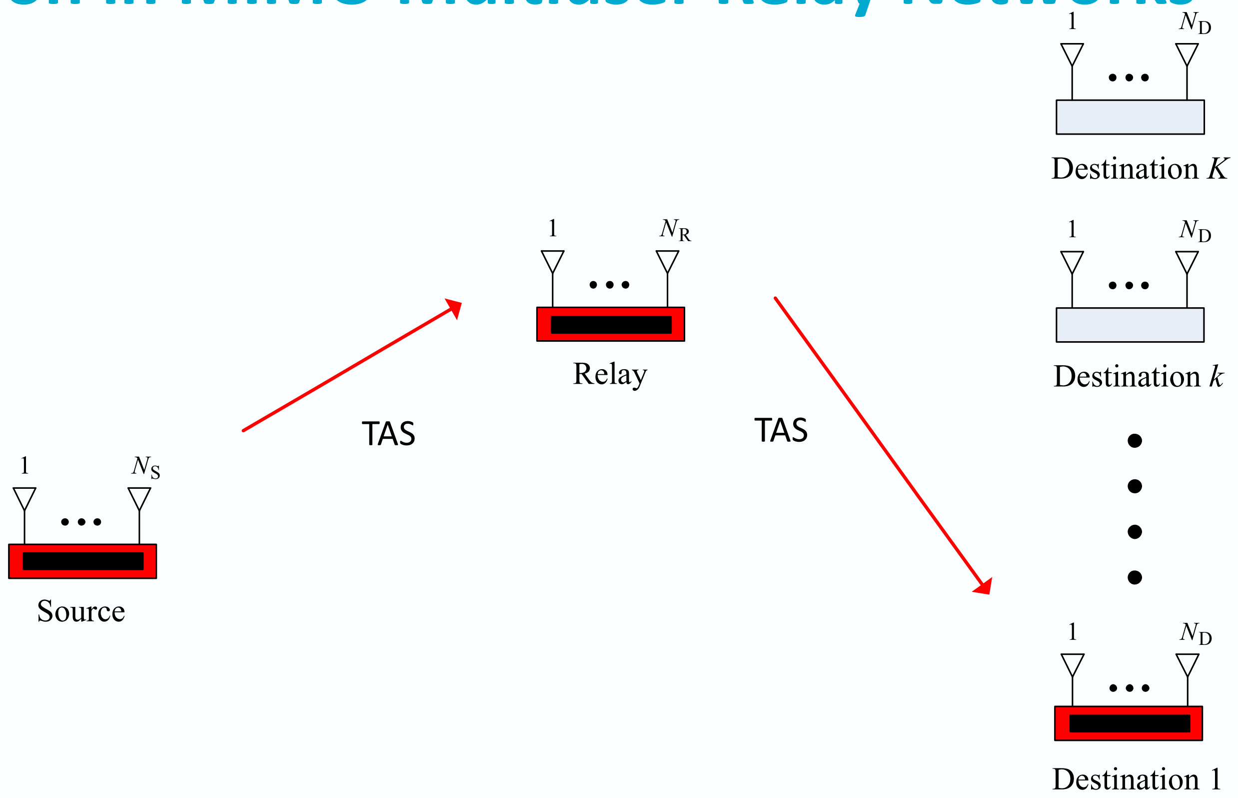
- Benefits: Cooperative diversity typically comes at the expense of N+1 orthogonal channels for the source and all the relays to transmit. Relay selection offers a low network complexity without spectral efficiency loss since only two orthogonal channels are required.

Selection Diversity vs All-Participate in Cooperative Networks



SD can outperform All-participate without added complexity and bandwidth requirements. For the comparison with MRC, we divide the transmit power by the number of relays, N.

Application in MIMO Multiuser Relay Networks



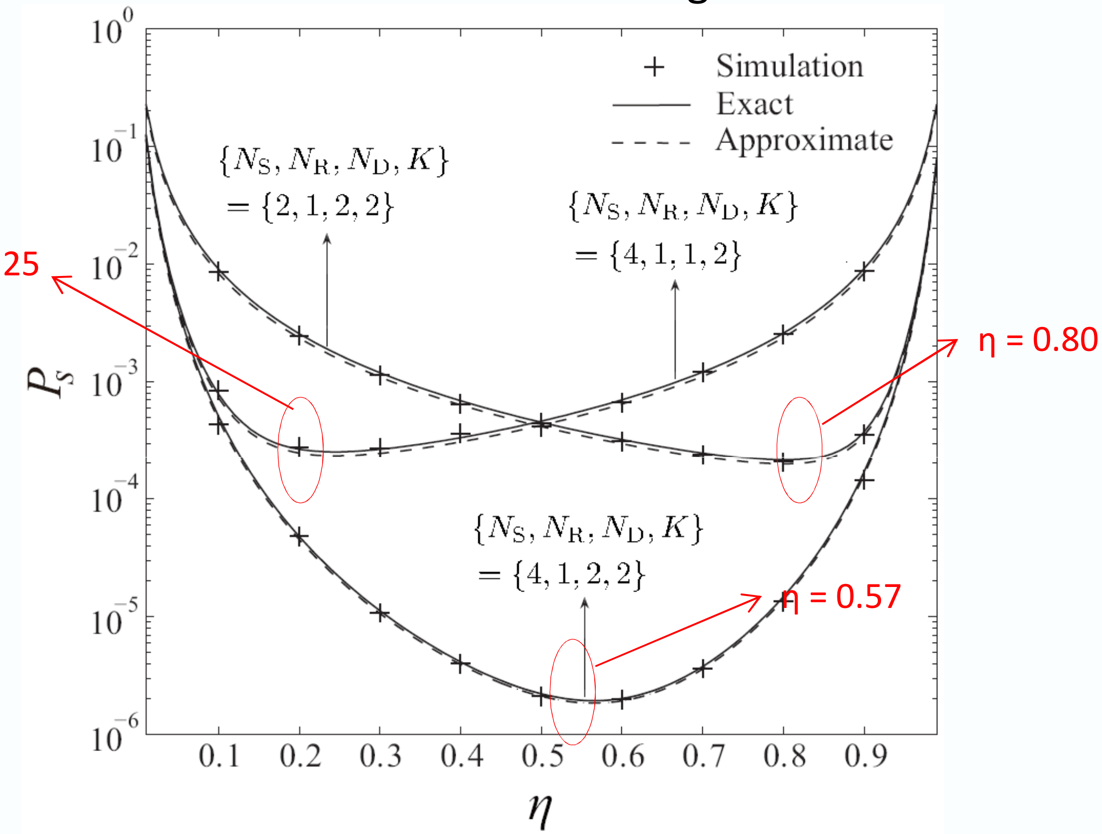
Exploit both multi-antenna diversity and multiuser diversity with low complexity and low feedback overhead in multiuser relay networks

Viable option for emerging standards, e.g., IEEE 802.16j multihop relay networks and IEEE 802.11s mesh networks.

Finding: Diversity Order: $G_d = N_{\mathrm{R}} \times \min\{N_{\mathrm{S}},\ N_{\mathrm{D}}K\}$

Application in MIMO Multiuser Relay Networks

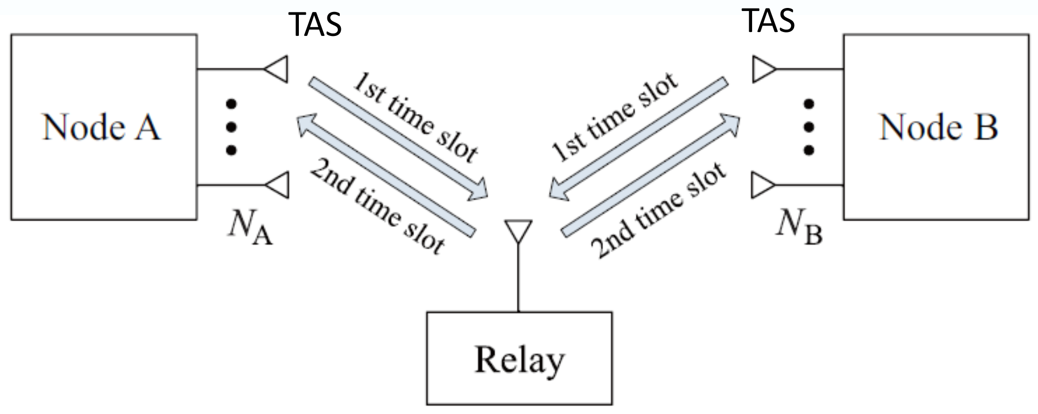
SER versus power allocation η between the source and the relay for different antenna configurations.



The optimal power allocation varies according to the number of destinations and the number of antennas at the source, the relay, and the destinations.

P.L. Yeoh, M. Elkashlan and I.B. Collings, "MIMO Relaying: Distributed TAS/MRC in Nakagami-m Fading", IEEE Trans. Communications, Vol. 59, No. 10, pp. 2678-2682, October 2011.

Application in Two-Way MIMO Relaying

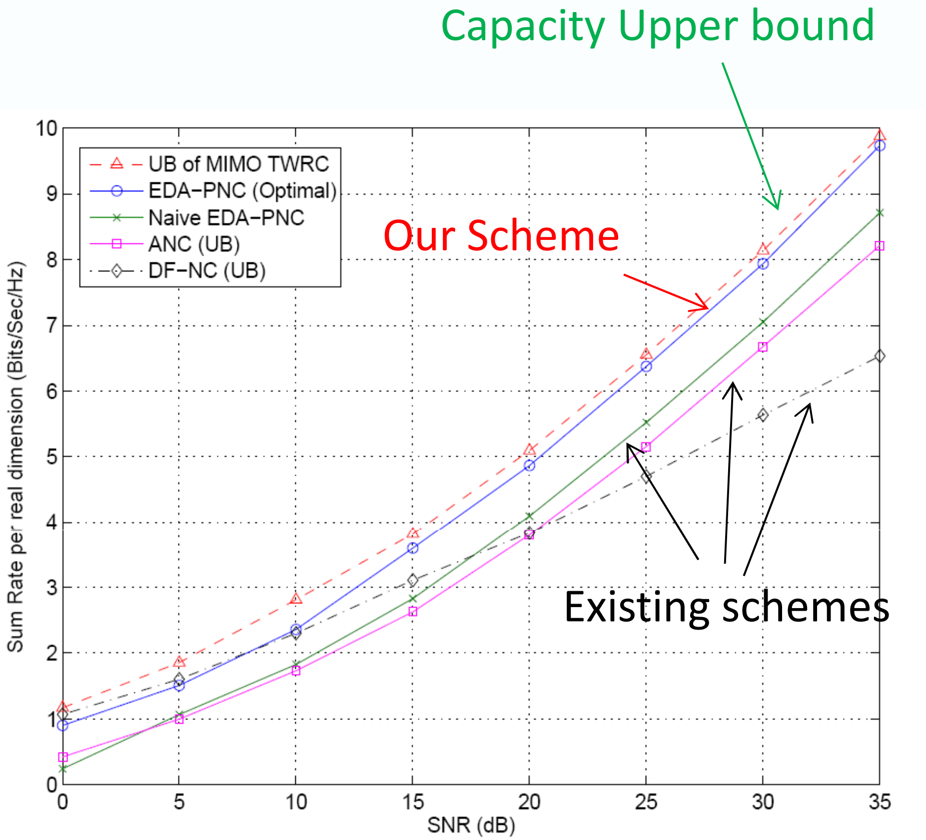


Motivation: Transmit/Receive antenna selection exploits the multi-antenna diversity in two-way MIMO relaying in a low complexity manner.

One possible Algorithm: A single transmit/receive antenna is selected at each node.

Benefits: The full diversity order of $\min\{N_{\mathrm{A}}, N_{\mathrm{B}}\}$ is achieved, as if all the transmit antennas were used, e.g., beamforming.

Eigen Direction Alignment PNC for MIMO TWRC



This figure shows a 2 by 2 MIMO two-way relay channel case.

The gap between our scheme and the capacity upper bound is almost unnoticeable at a medium-to-high SNR.

Our proposed scheme outperforms existing amplify-and-forward and decode-and-forward scheme by up to 40% in spectral efficiency at practical SNR levels.

T. Yang, X. Yuan and I.B. Collings, "Reduced-Dimension Eigen-Direction Alignment Precoding for MIMO Two-Way Relay Channels", in the Proc. of the IEEE Int. Symp. on Personal Indoor and Mobile Radio Communications (PIMRC), Workshop on Network Coding in Wireless Relay Networks, Sydney, Australia, pp. 71-76, September 2012.

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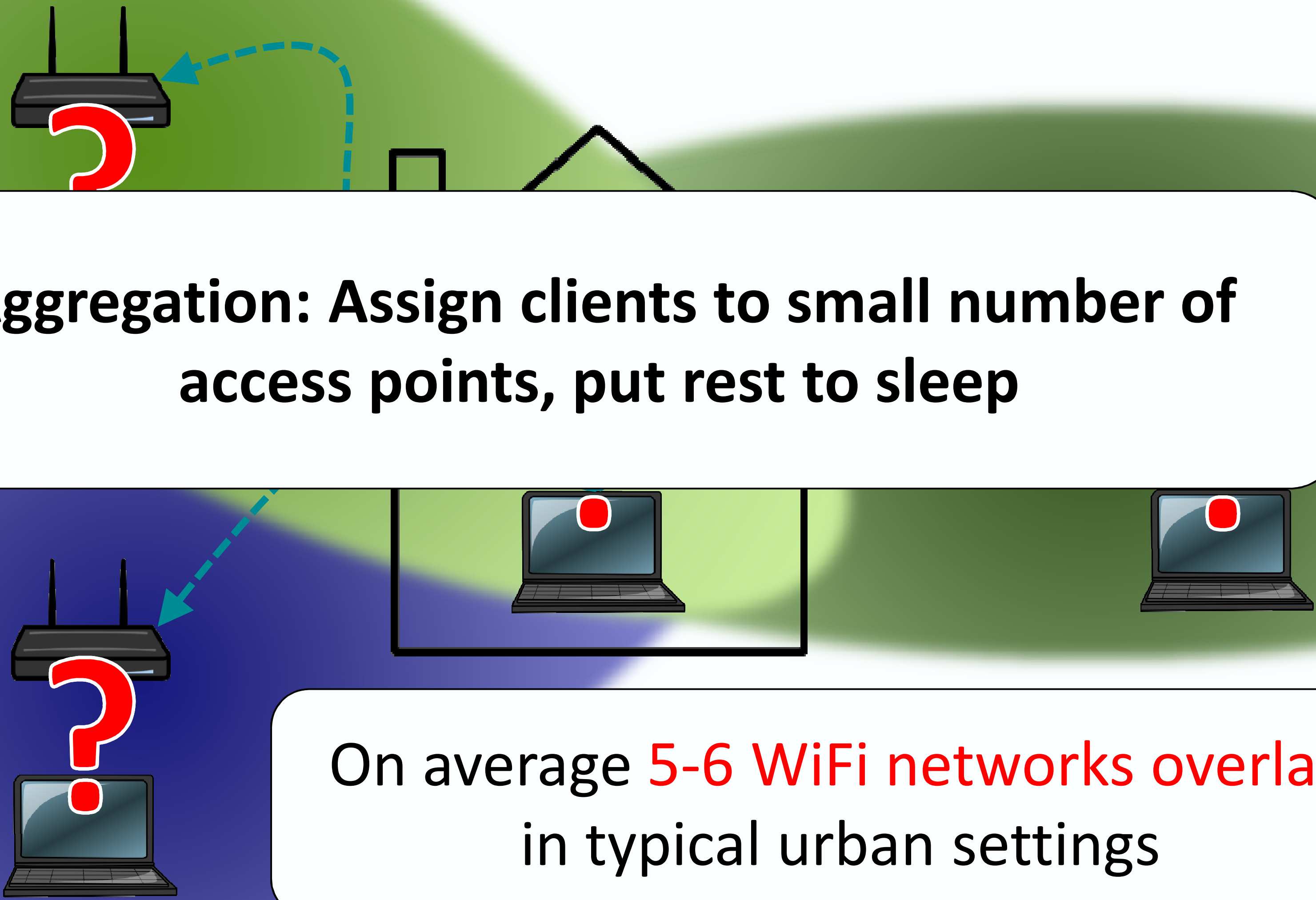
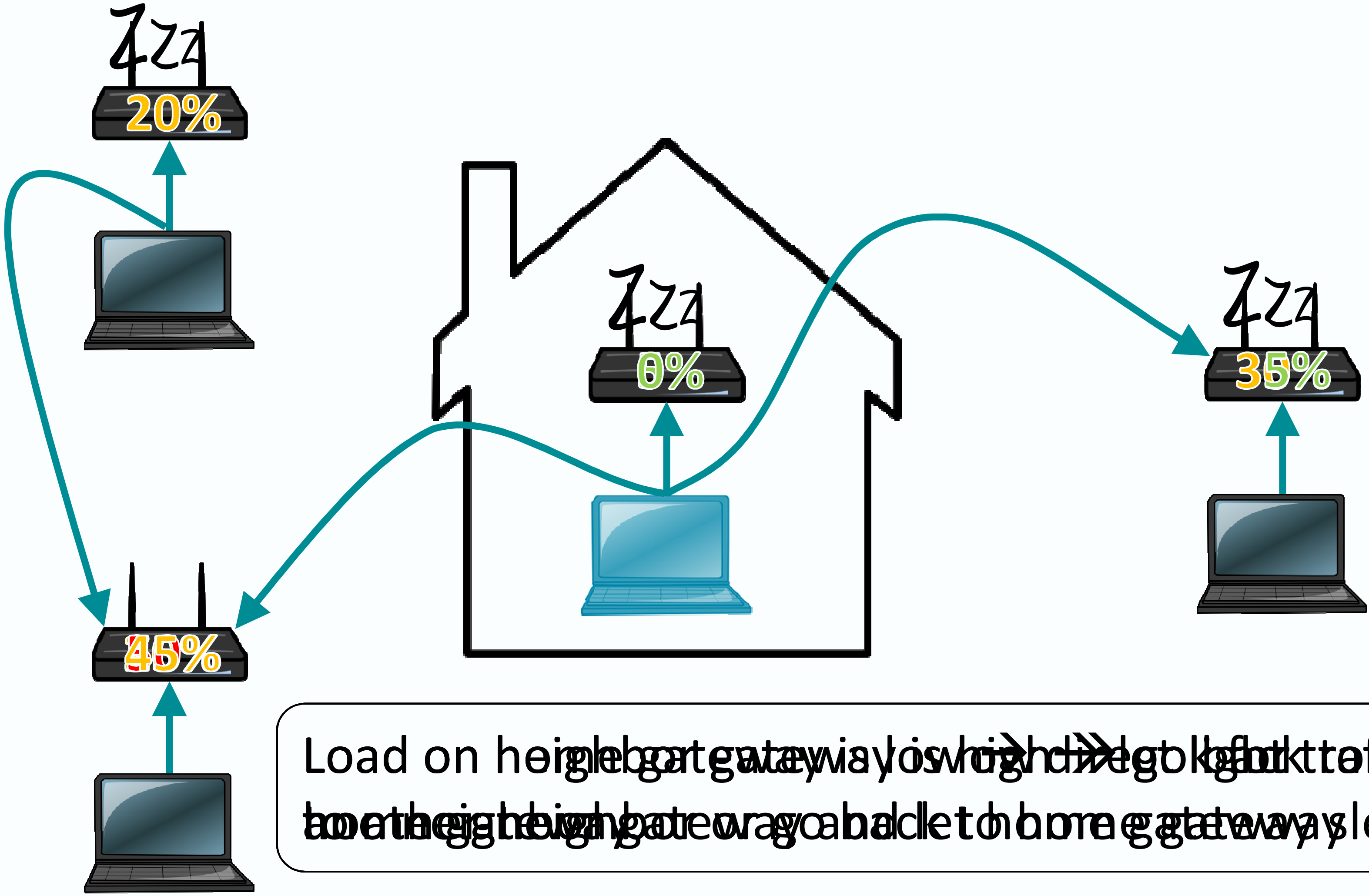
Greening via Aggregation



Aggregation: Assign clients to small number of access points, put rest to sleep

On average 5-6 WiFi networks overlap in typical urban settings

Distributed Implementation (Canini, Sigcomm'11): Broadband Hitch-Hiking (BH^2)



Load on home gateway is low → redirect traffic to neighbor gateway and let home gateway sleep

Load on neighbor gateway is high → go back to home gateway

Issues with Distributed implementation of Cooperative Sleeping

- Client-side machinery:
  - Complex to install and maintain:
    - interface virtualisation
    - reverse network address translation (NAT)
    - traffic snooping
  - Requires updating clients:
    - Many household devices, heterogeneous OS
    - Non-compliant / malicious clients can cheat system
- Sub-optimal: no bounds on performance
- Fairness:
  - Unfair sharing of bandwidth and energy costs

Our approach: Centralised Implementation

- Central entity computes optimal assignments
- Minimise: Power $P = \sum_j W_j X_j$
  - X_j : binary variable 1 if AP-j selected, 0 otherwise
  - W_j : weight of AP-j (used to control fairness)
- Constraints:
  - $\forall i, j$: $x_{ij} \leq e_{ij}$, i.e. client-i can connect to AP-j only if link is feasible
  - $\sum_j x_{ij} = 1$, i.e. client-i can connect to only one AP
  - $\sum_i b_i x_{ij} \leq C_j$, i.e. total bandwidth needed by clients connected to AP-j does not exceed capacity of AP-j
  - $\sum_i x_{ij} \leq X_j \sum_i e_{ij}$, i.e. AP-j is turned on if any client connects to it.

Heuristic Solution

- Greedy algorithm:
  - Pick (previously unpicked) AP that covers largest number of uncovered clients, normalised to weight
  - Repeat until all clients covered
- Solution within log(n) of optimal (n = # clients)
- Assignment of clients to APs:
  - Clients with (rate > threshold θ) stay with home AP
  - Other clients moved to "least cost" AP
  - AP-cost = energy-cost + guest-data-cost
    - Exponentially averaged
    - Tracking of cost helps maintain long-term fairness

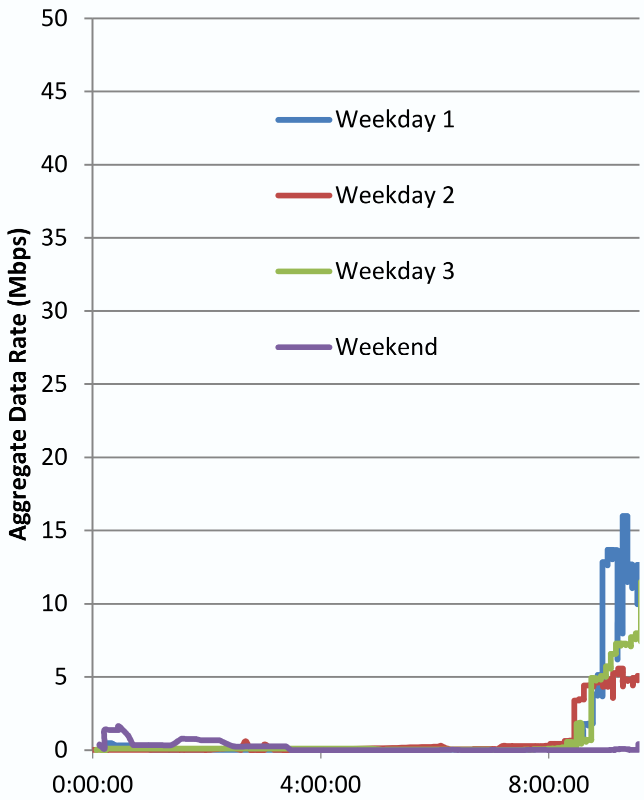
Evaluations: Trace Data

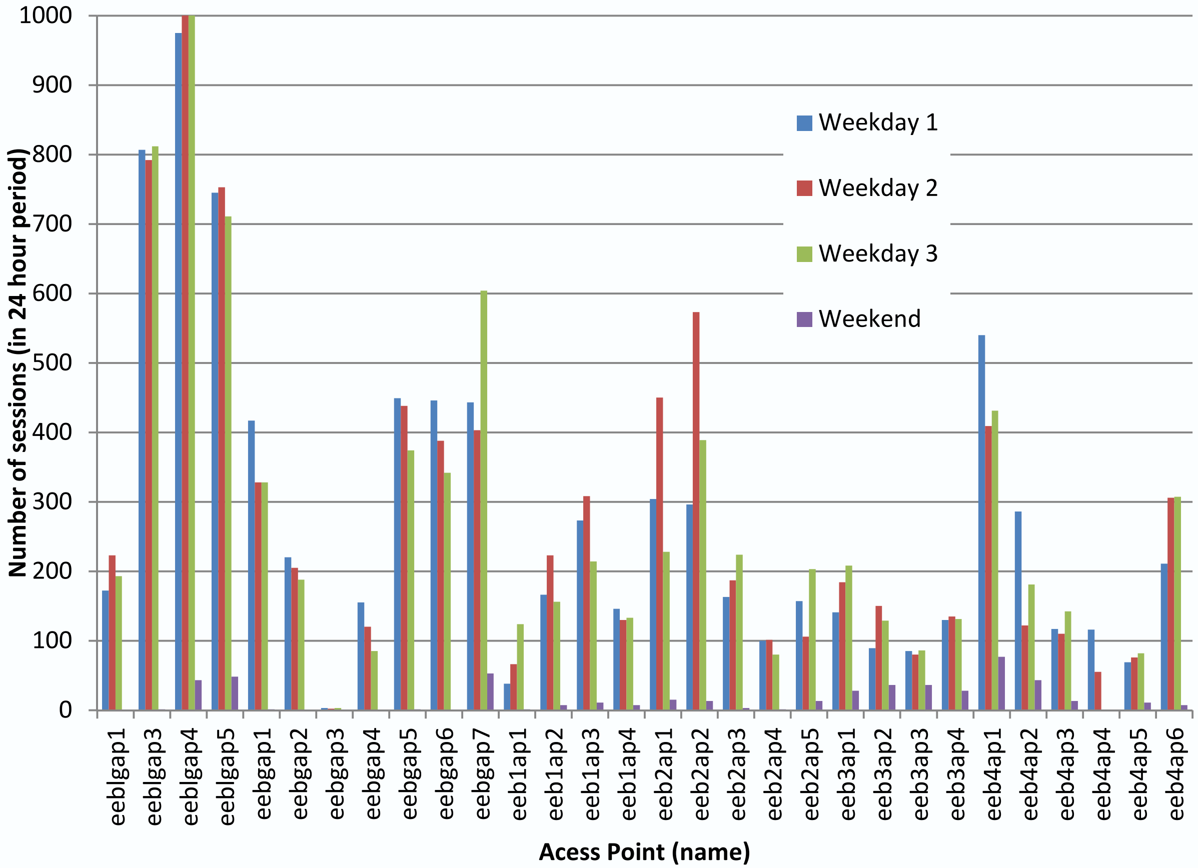
Campus building with 30 APs

4 x 24-hour traces with ~26K client sessions

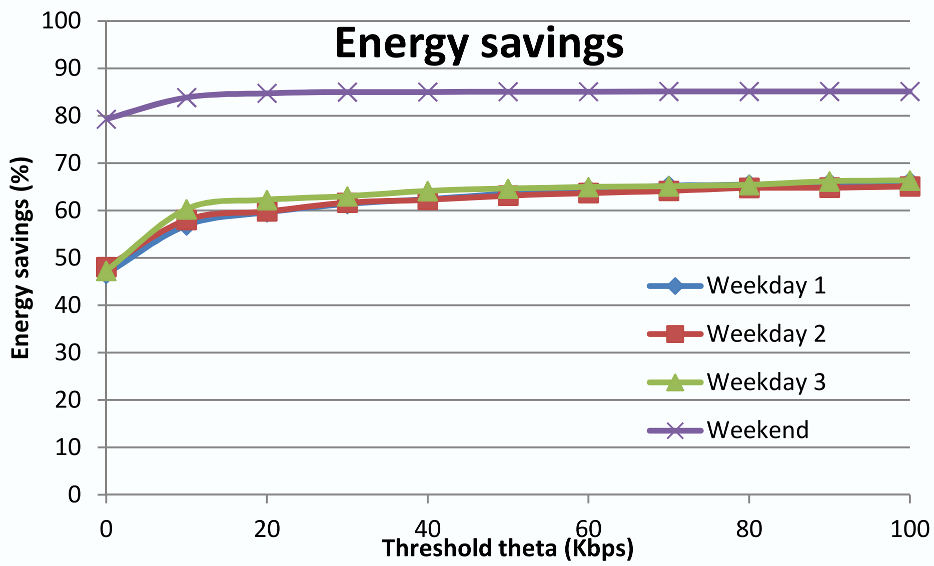
Client on average sees 5.8 APs

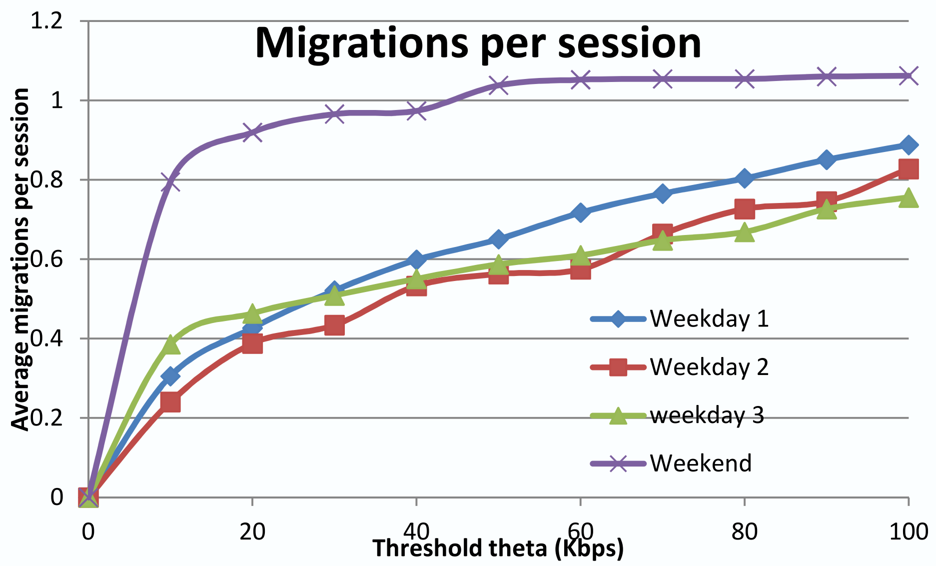
90% of sessions have avg. data rate < 20Kbps





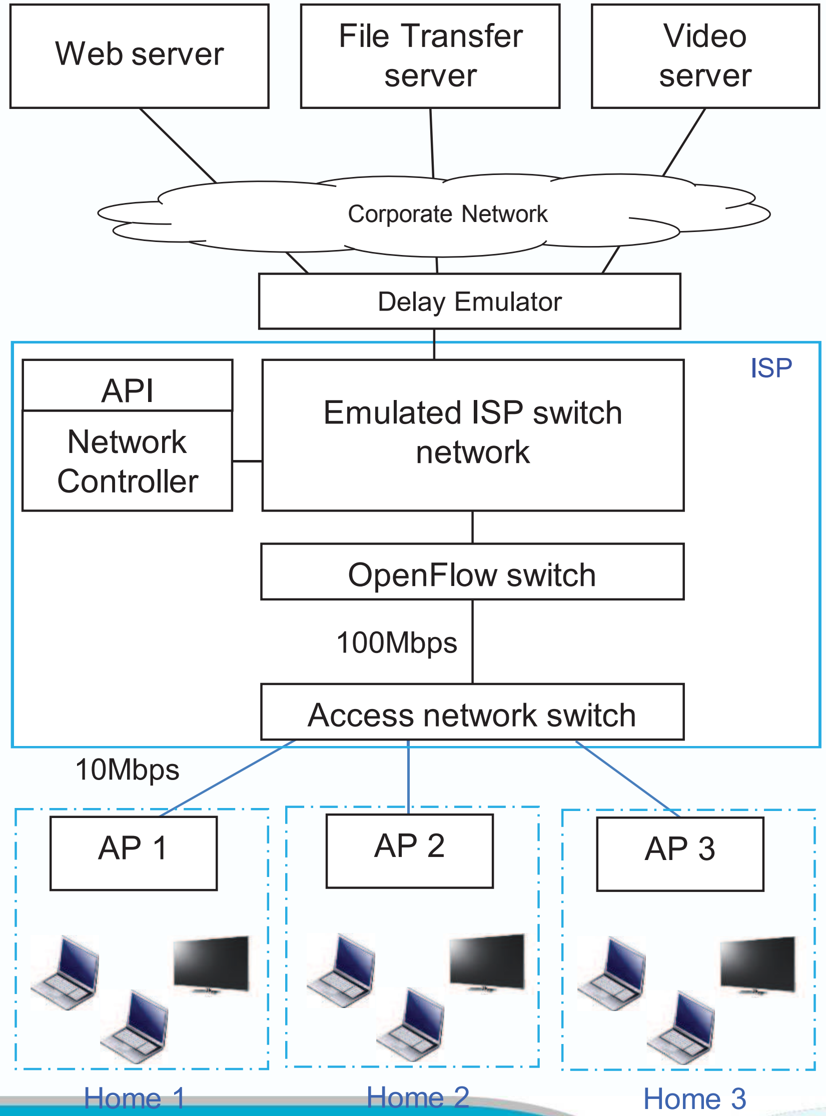
Simulation Results



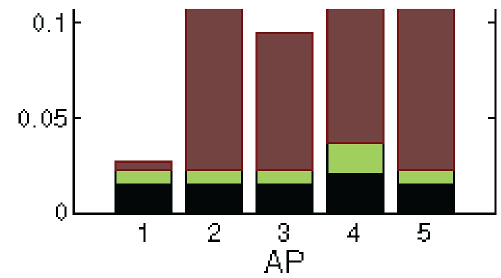


- 50-70% energy savings possible (85% on weekends)
- Increasing migration threshold increases energy savings, but also increases migration disruptions
- Increasing fairness (marginally) decreases energy savings

Prototype: 6 Households



- Commodity AP: TP-LINK DD-WRT
- Home and guest SSID
- WiFi device discovery, NetFlow
- Controller runs algorithm
- Clients unmodified:
  - PowerShell scripts
  - Video, Skype, Browsing


0.1
0.05
0
1
2
3
4
5
AP

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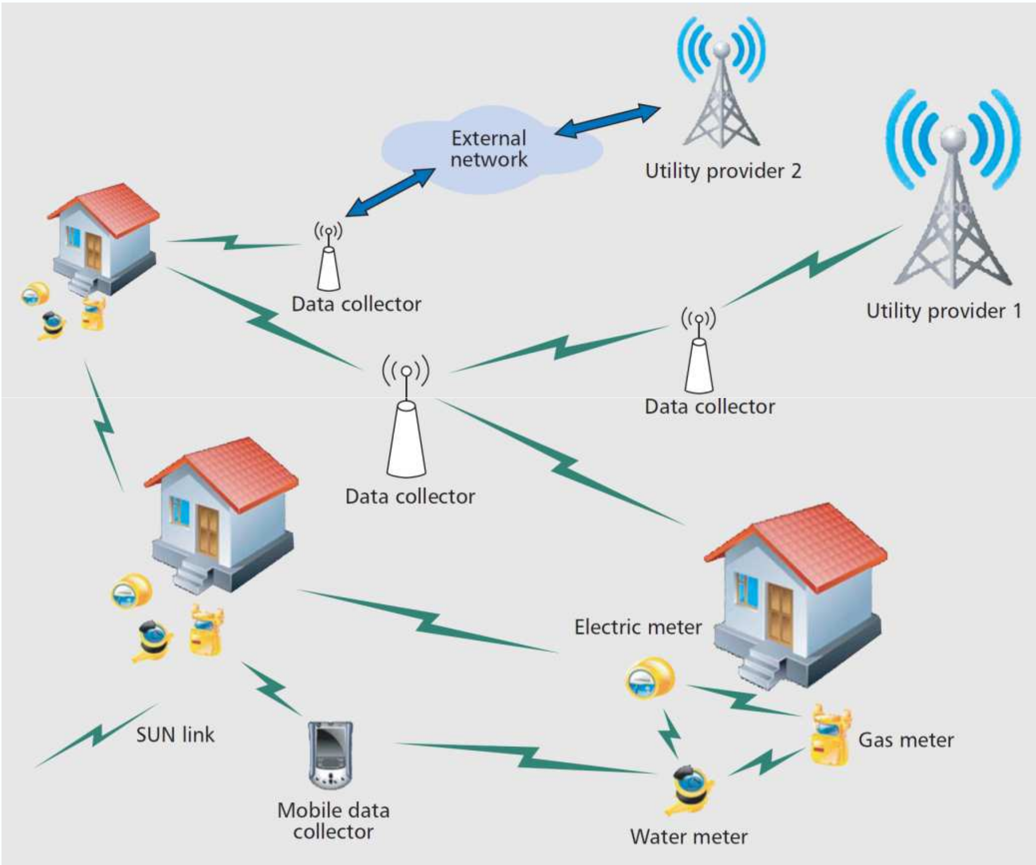
IEEE 802.11 for M2M Networks

IEEE 802.11 Task Group AH

- Started July 2010, targeting standard release IEEE 802.11ah in 2014
- Sub 1 GHz spectrum
- Longer reach – 1 km
- More devices – 6000 STAs per AP
- Traffic: periodic, light
  - Uplink: meter reading
  - Downlink: control message

Potential issues

- Physical layer
- MAC
- Power Saving *

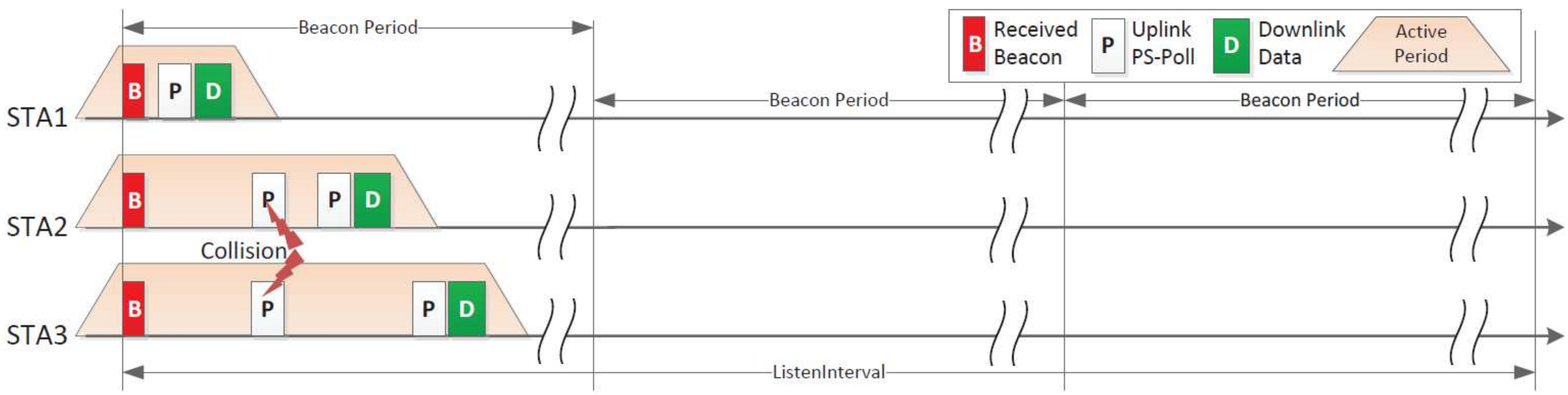


"Smart Utility Networks in TV White Space," IEEE Comms. Mag. July 2011

Issues on M2M Communication Networks

When multiple STAs have aligned wakeup periods

- High collision: p=30% when as few as 15 STAs aligned (out of the 1000's)➔ higher delay,
- STAs have to wake up longer (consume more energy) than STA w/o collision.
- Bad for a M2M Communication Network:
  - Designed network lifetime = 5 years
  - Some 5% (aligned) nodes die earlier (after 6 months) due to aligned periods
  - Whole system collapse!



(a) Collision between PS-Polls results in longer active periods

Collision probability

Find the relationship between

- Transmit probability matrix T and collision probability matrix C

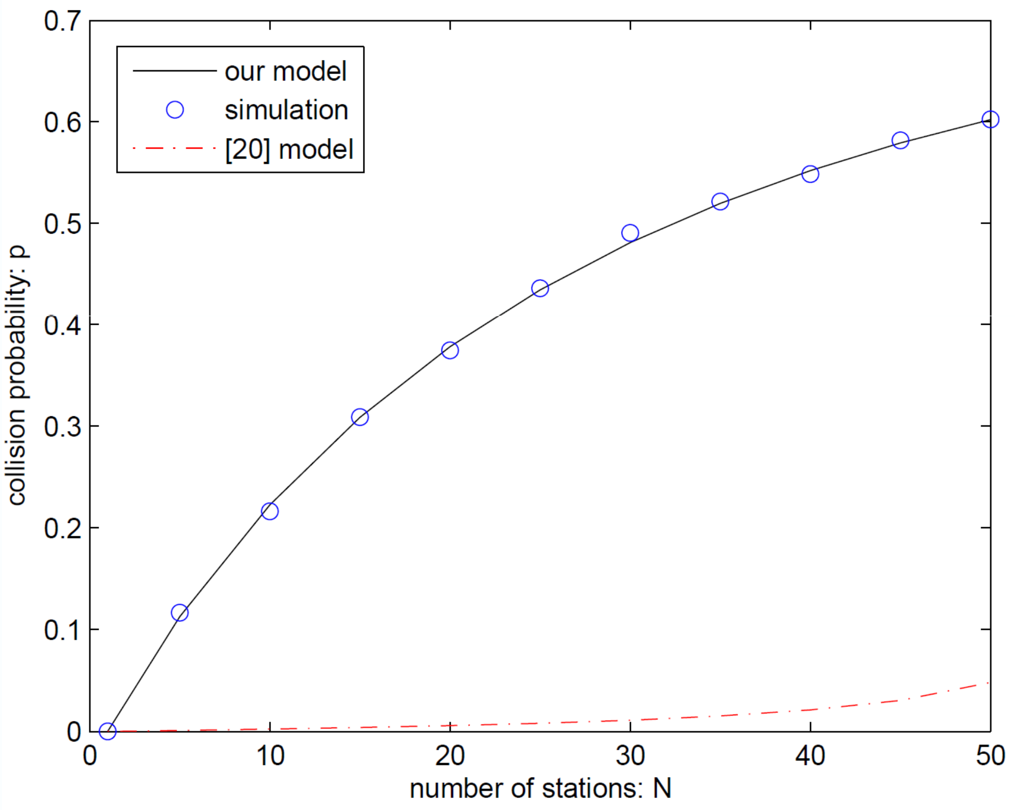
$$\mathbf{T}_{i+1,k} = \begin{cases} 1/W_0, \text{ for } i=0, j=1,..,W_0, \\ \sum_{j\in\mathcal{B}(i,k)} \frac{1}{W_i}\mathbf{C}_{i,j}, \\ \quad \text{for } i=1,..s, \mathcal{B}(i,k)\neq\emptyset, \\ 0, \text{ else}, \end{cases}$$

$$\mathbf{C}_{i,k} = \mathbf{T}_{i,k}(1-[1-\sum_{j=0}^{s}\mathbf{T}_{j+1,k}]^{N-1}),$$

Collision probability solved

- Match simulation results

$$p(N) = \frac{\sum_{i=0}^{s}\sum_{k=1}^{W_{tot}}\mathbf{C}_{i+1,k}}{\sum_{i=0}^{s}\sum_{k=1}^{W_{tot}}\mathbf{T}_{i+1,k}}.$$



Our Proposal: Power Save with Offset ListenInterval (PL-OLi)

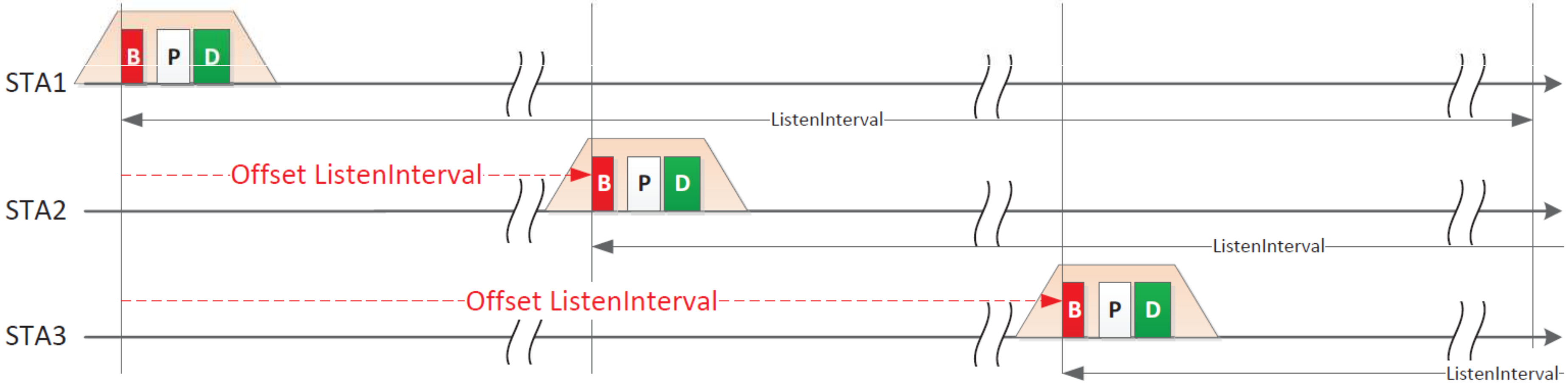
Beacon #	0	1	2	3	4	5	...	$N_B - 1$
Occupancy	1	1	1	0	1	0	...	1

AP maintains a beacon occupancy table (BOT)

- Records the number of PS STAs at each beacon interval

AP find the lowest Beacon interval for the STA_m

- Search BOT for lowest entry
- Calculates an offset to be applied to the Listen Interval



(b) Collision is avoided by adding an offset to the ListenInterval in OLi

Performance Analysis – Energy

Energy consumption to retrieve a packet

$$E(N) = P_S(1)E_S + \sum_{k=2}^{W_{tot}} P_S(k)(E_S + \sum_{j=1}^{k-1} e(j)).$$

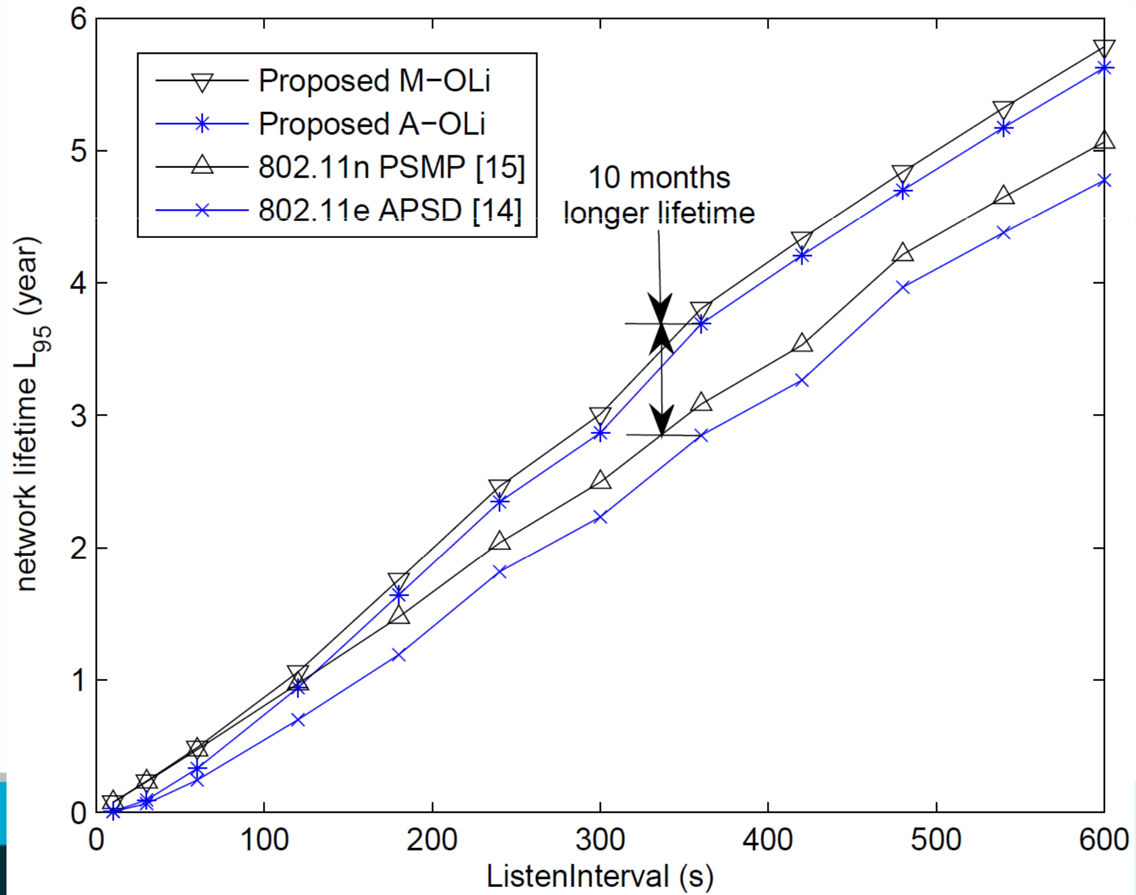
– where $e(k) = \frac{P_N(k)E_N + P_{XS}(k)E_{XS} + P_C(k)E_C + P_{XC}(k)E_{XC}}{1 - P_S(k)}.$

PS-OLi improve lifetime

– by up to 30% (10 months)

Improves scalability

– By up to 40%
(scale up to 5800 nodes)



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Greening Enterprise Ethernets

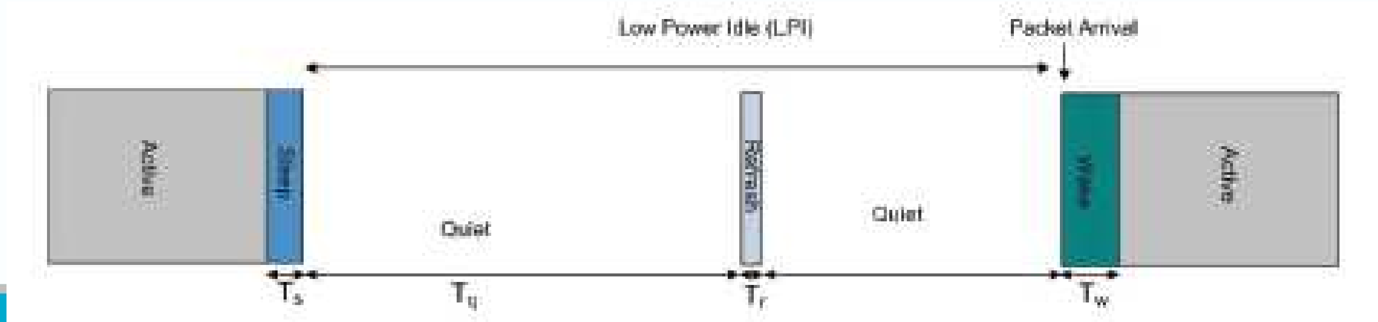
Ethernet switches dominate enterprise networks

(7.9 TWh per-year in the US)

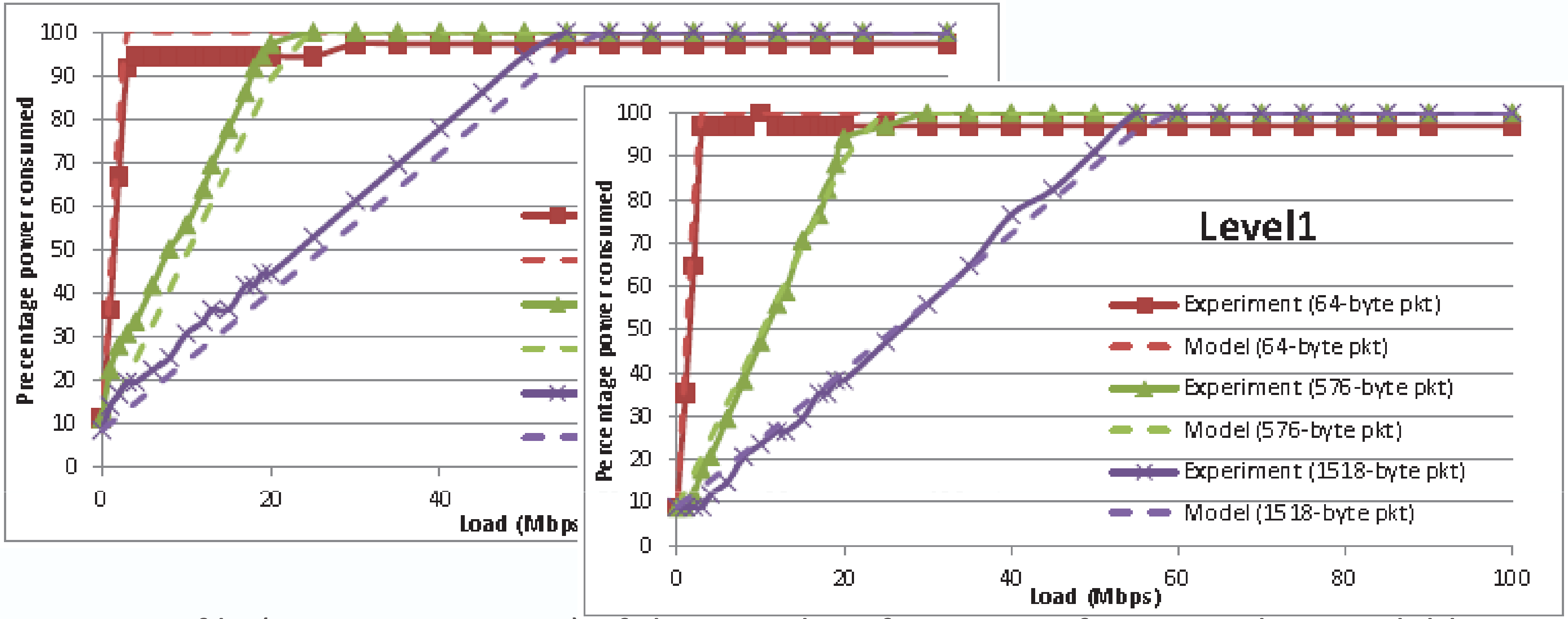
M. Mostowfi, K. Christensen, “Saving energy in LAN switches: New methods of packet coalescing for energy efficient ethernet”, in: Proc. International Green Computing Conference, IGCC ’11, IEEE Computer Society, Washington, DC, USA, 2011, pp.1–8.

IEEE 802.3az: Energy Efficient Ethernet (EEE)

- Introduces “low power idle” (LPI) mode
  - Interface put to “sleep” during idle periods
  - Periodic wake-up to maintain sync and check for packets
- Energy savings very dependent on traffic profiles



EEE Savings vs. Traffic Load and Packet Size

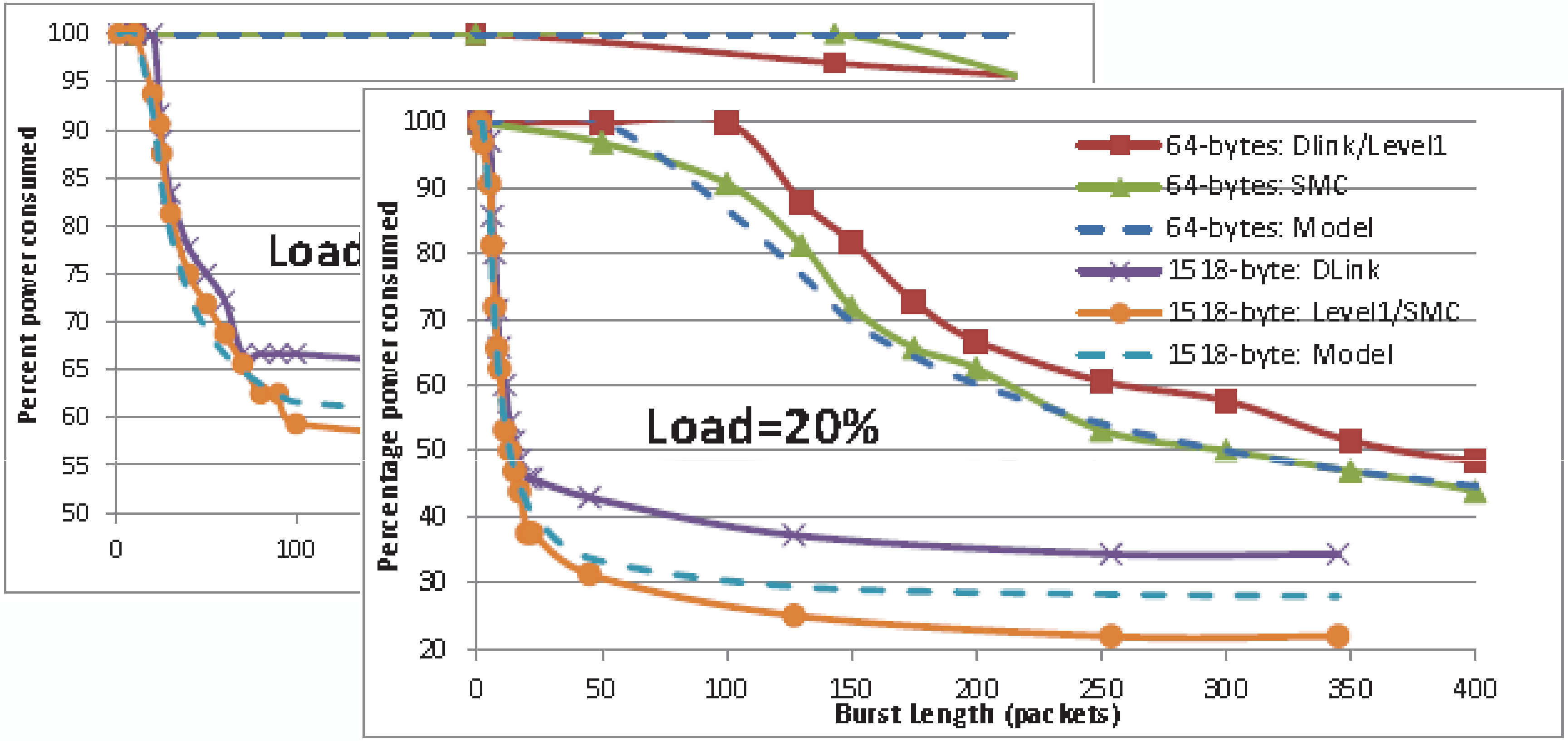


- New profile (via measurement) of the actual performance of EEE switches available on the market.
- A new (and simple) model that is able to predict the energy savings with EEE based on simple parameters such as traffic load, packet size, and traffic burstiness.

Savings roughly linear in traffic load

Savings larger for larger packets (for same load)

EEE Savings vs. Traffic Burstiness

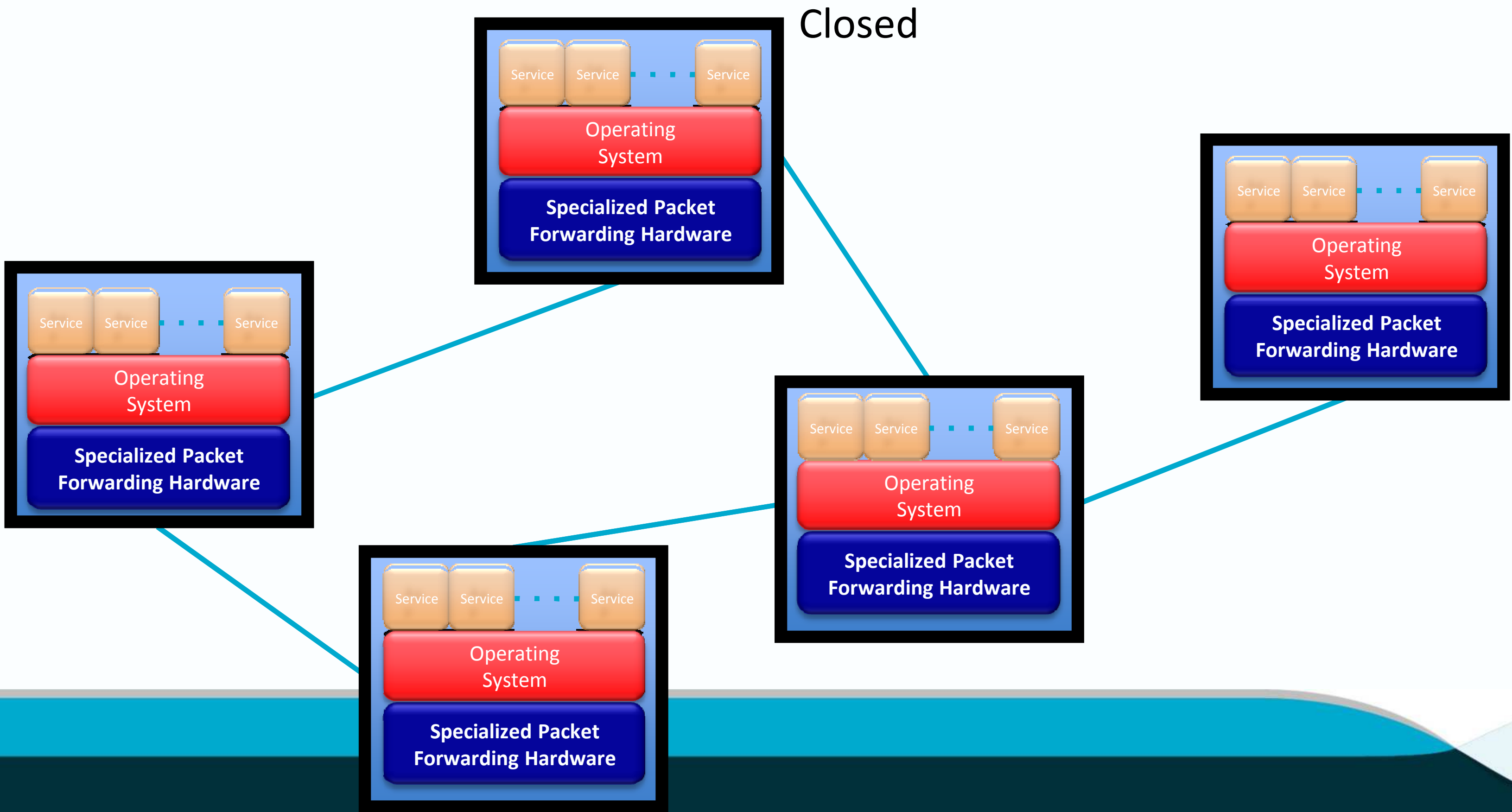


- Burstier traffic better for energy savings
  - Longer sleep periods

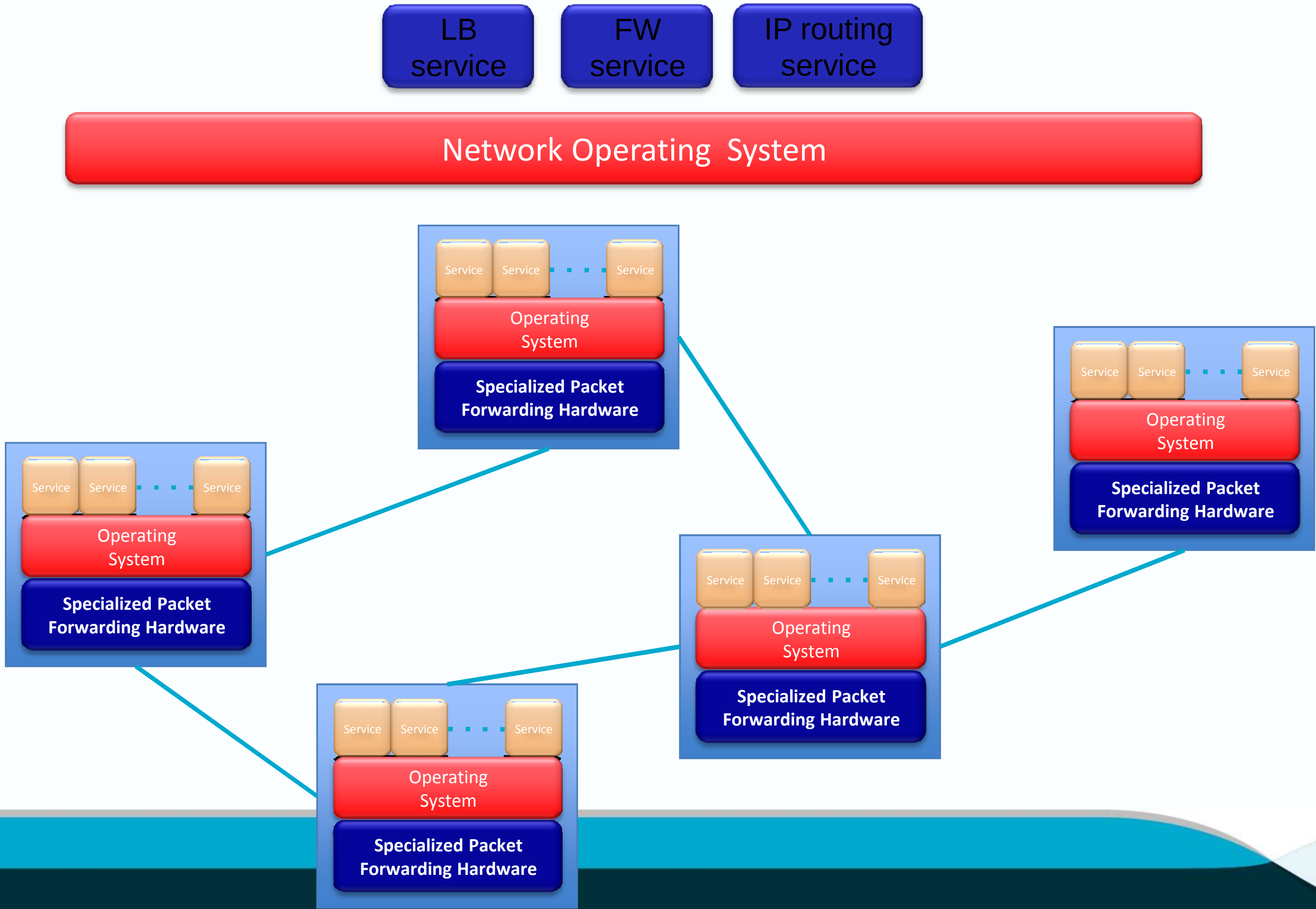
Outline

- Energy in WLAN Access
- Basic sleep modes
- Cooperation in Wireless Networks
- Cooperative Sleep Modes in WLAN
- Machine to Machine communications
- Energy Efficient Ethernet
- Software Defined Networking

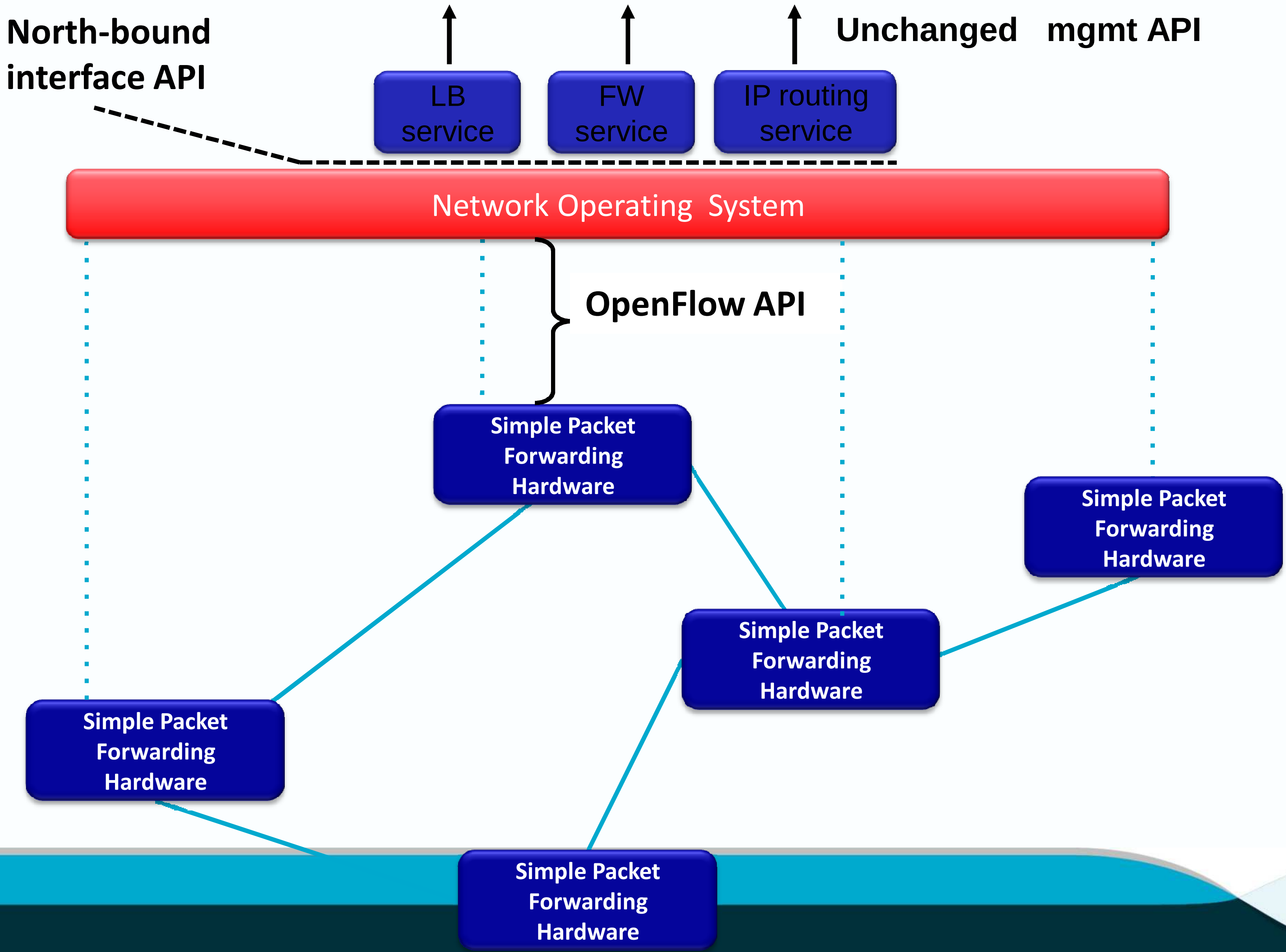
Current Internet
Closed to Innovations in the Infrastructure



"Software Defined Networking" approach to open it



The “Software-defined Network”



AusSDN – an SDN Infrastructure Platform

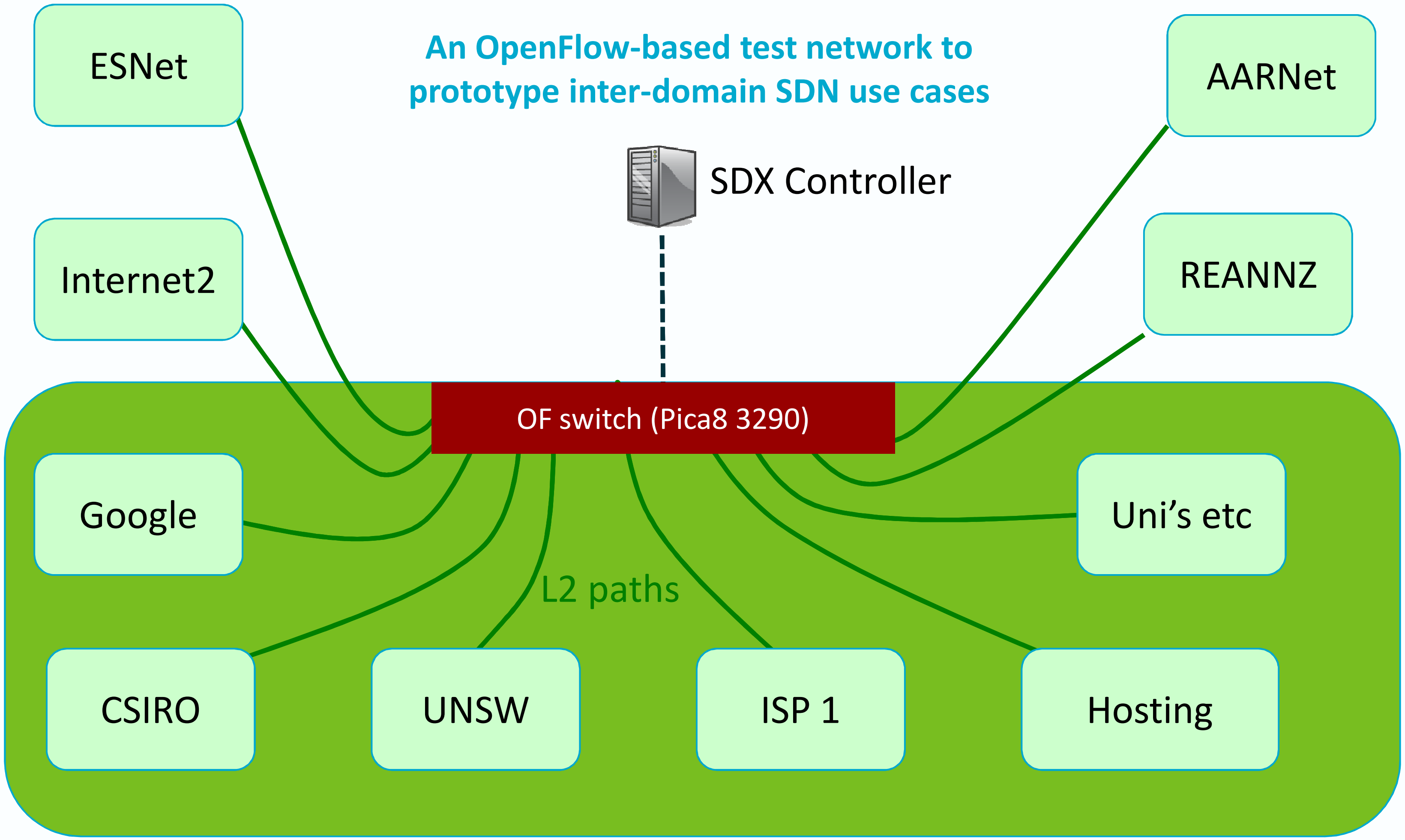
SDN test network in Australia based around an SDX (SDN Internet Exchange)

- Partners can prototype research
- Leverage collective capability to seek resources from government and other sources (e.g. LIEF)
- Involve other organizations (Google, NICTA, ISPs, vendors?)
- Develop student skills in SDN (mentoring, projects, internships)
- Have an impact on the Australian NBN and networks of the future

AusSDN

Australian Open Network Experimental Test-bed

An OpenFlow-based test network to prototype inter-domain SDN use cases



Summary

- Energy is a major factor for wireless access networks
- Cooperation between nodes can have significant benefits
- Cooperative Sleep Modes in WLAN have great potential
- Sleep modes in M2M communications are more challenging
- SDN offers hope for an Energy Efficient Ethernet

Thank you

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