CMES: Collaborative Energy Save for MIMO 802.11 Wireless Networks

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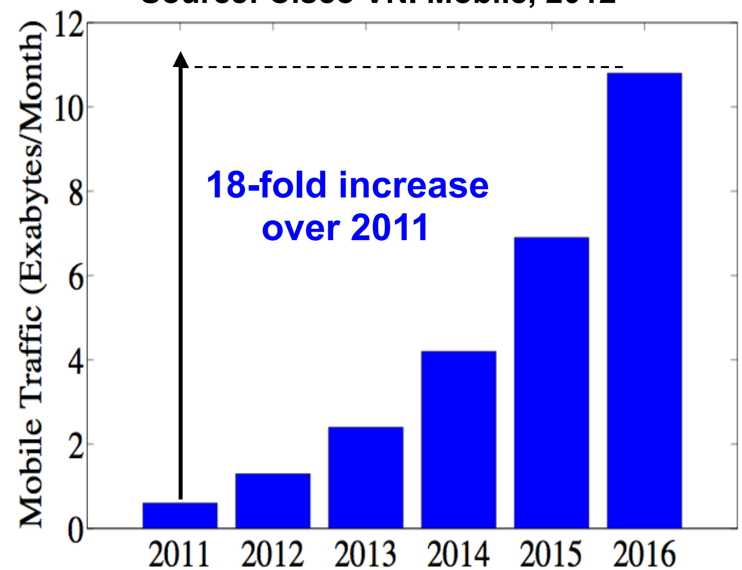
Emerging wireless

5.9 billion mobile subscriptions in 2011 (Source: ITU)

HD 1080p **video** rate: **50Mbps**
WiFi **802.11a/g** speed: **~30Mbps**

Source: Cisco VNI Mobile, 2012



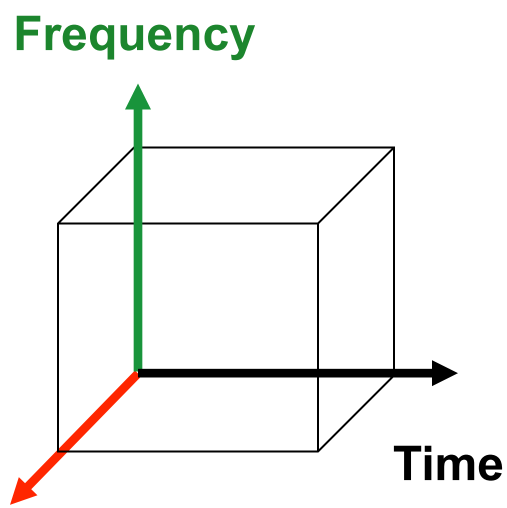
Pervasive wireless **+** **High-speed applications** **=** **Large wireless traffic volume**

Call for transition to **gigabit wireless**

MIMO gigabit wireless

$$Capacity = \begin{cases} W \cdot log_2(1+SNR) \\ \min\{N_t, N_r\} \cdot W \cdot log_2(1+SNR) \end{cases}$$

MIMO

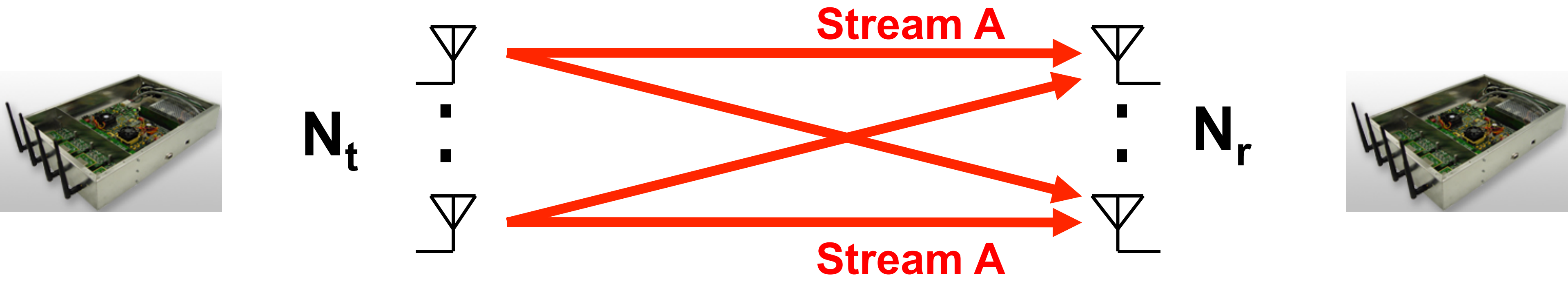


Space (Multiple Input Multiple Output, MIMO): Multiple antennas (N_t ,N_r)

MIMO exploits the space dimension to increase speed from ***megabit*** (***54Mbps*** in 802.11a/g) to ***gigabit*** **(*>6Gbps*** in 802.11ac)

MIMO: Spatial diversity

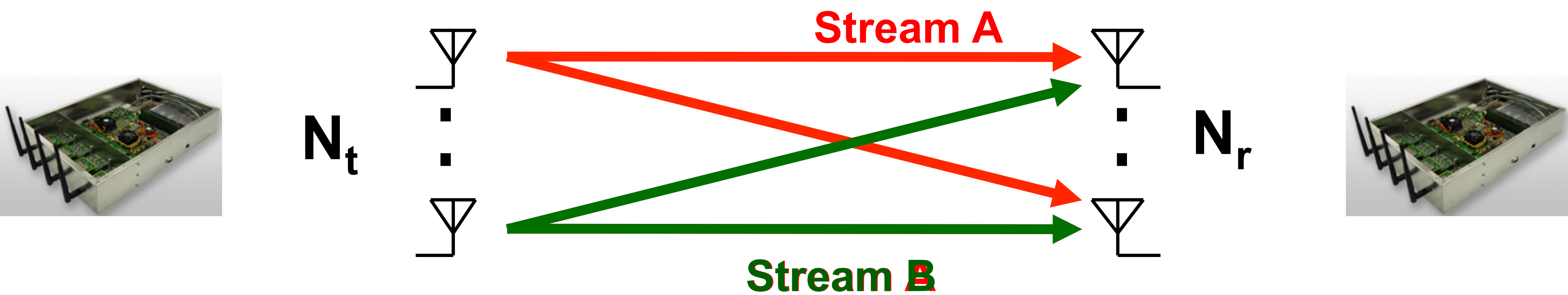
- **MIMO**: Multiple antennas at the sender (N_t) and receiver (N_r)



- **Spatial diversity** transmits <u>the same stream</u> from each antenna
  - More reliable transmission
  - Packer error rate: $P_e = 1/SNR^{Nt \cdot Nr}$

MIMO: Spatial multiplexing

- **MIMO**: Multiple antennas at the sender (N_t) and receiver (N_r)



- **Spatial multiplexing (SM)** transmits multiple independent streams simultaneously
  - Increased data rate
  - Capacity: $C = \min\{N_t, N_r\} \cdot W \cdot \log_2(1+SNR)$

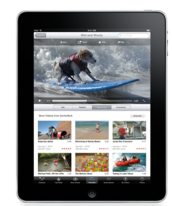
State of the Art 802.11 MIMO energy save

- Existing proposals seek to save energy at the receiver They adopt 3 guidelines:
  - Guideline 1: ***Activate antennas to increase speed***
    - Snooze (CoNEXT' 11)
  - Guideline 2: ***Deactivate antennas to save power***
    - IEEE 802.11n SMPS
  - Guideline 3: ***1-side antenna management to save energy***
    - MRES (ICNP' 11), EERA (MOBICOM' 12)

Activate antennas to increase speed

Is speed the right metric?

Application data rate = **3 Mbps (video)**



Sender

Receiver

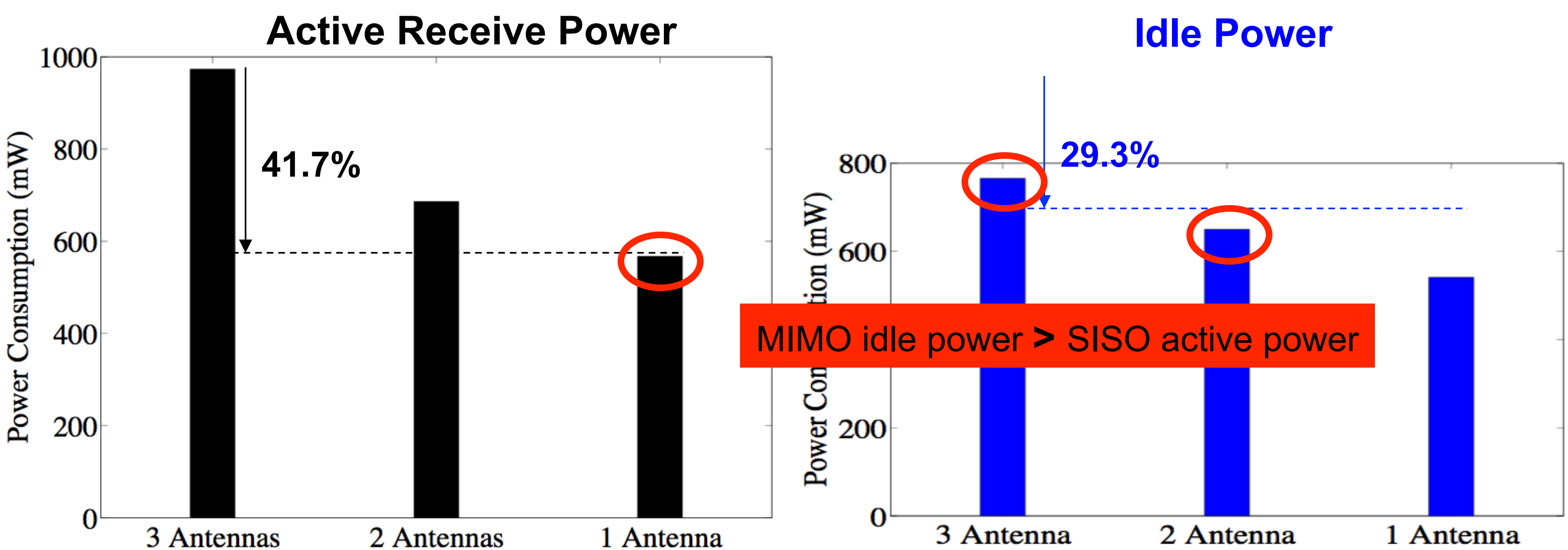
MIMO (3x3): 779.6 mW / 3 Mbps → 259.9 nJ/bit

Legacy(3x1): 547.8 mW / 3 Mbps → 182.6 nJ/bit

Legacy offers ***29.7%*** energy savings over MIMO at the receiver

Cause of MIMO Poor Performance

- MIMO circuit blocks consume power *proportional to the number of antennas*
- Measurements MIMO 802.11n radios:



Speed comes at a cost of **increased MIMO power** consumption

Deactivate antennas to save power

Is power the right metric?

Application data rate = 50 Mbps (HD video)

Sender

Receiver

MIMO (3x3): 973.5 mW / 46.35 Mbps → 21 nJ/bit
Legacy(3x1): 567.6 mW / 12.52 Mbps → 45.3 nJ/bit

MIMO offers ***53.6%*** energy savings over legacy at the receiver
(MIMO speed compensates for MIMO power consumption)

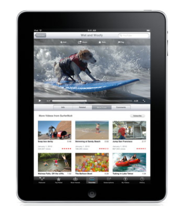
⇒Need to consider Watt/performance

One-sided energy management

Receiver-optimal may not be energy optimal for the:
a) transmitter, b) system (transmitter+receiver)

Sender

Application data rate = 3 Mbps (video) →



Receiver

Transmitter consumes ***x2*** more power

Receiver's optimal (3x1): 547.8 mW / 3 Mbps → 182.6 nJ/bit
Transmitter (3x1): 1012.7 mW / 3 Mbps → 337.6 nJ/bit
System (3x1): 1560.5 mW / 3 Mbps → 520.2 nJ/bit

System's optimal (1x2): 1446.8 mW / 3 Mbps → 482.3 nJ/bit

Transmitter-receiver collaboration is required for system-wide energy savings

CMES: Collaborative MIMO Energy Save

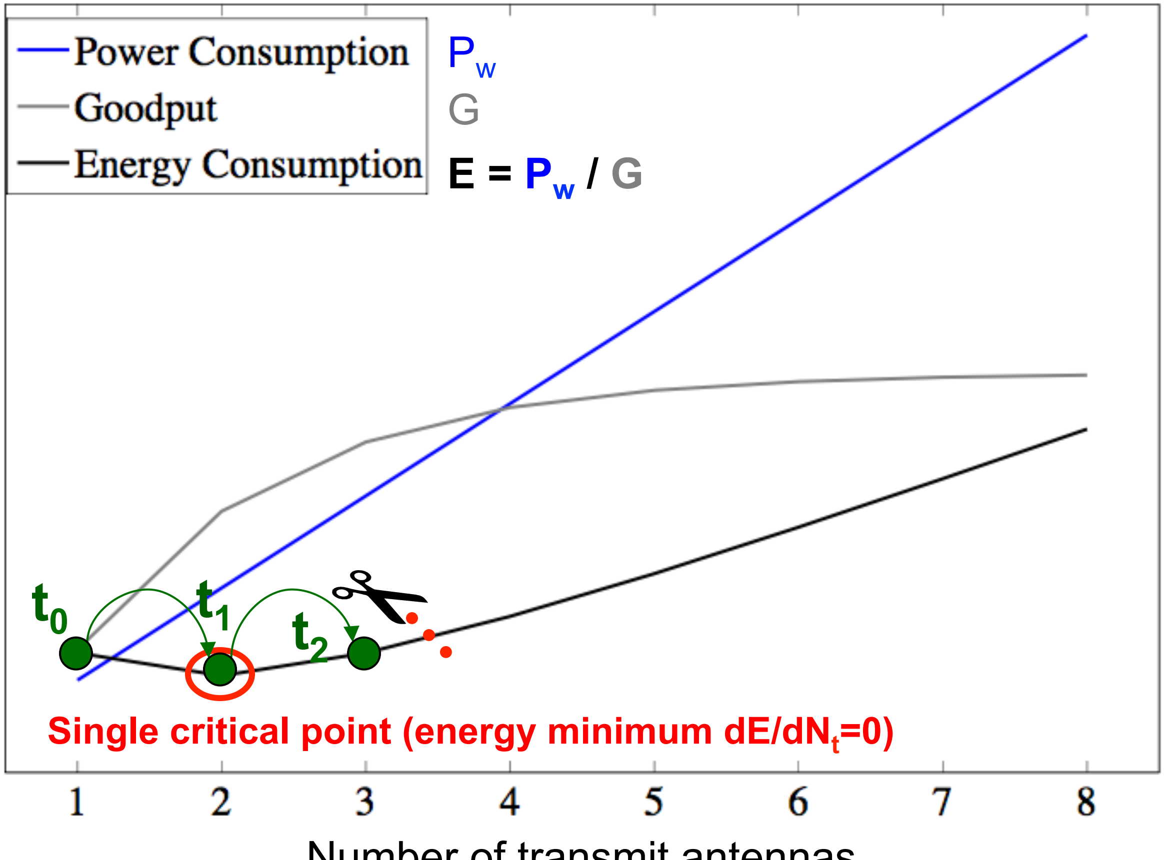
Identify the system's energy optimal antenna setting

- Metric: Power / Goodput (***Joule / bit***)
- Power (P_w) is the sum of processing (P_p) and circuitry (P_c) power
  - $P_w = T_{Active} \cdot P_{w,Active} + T_{Idle} \cdot P_{w,Idle} + T_{Sleep} \cdot P_{w,Sleep}$
- Goodput is calculated by sampling the available antenna settings
  - CMES can identify the energy optimal without sampling all the available antenna settings

Scalable, Optimal Sampling

For a fixed number of transmit or receive antennas there is only a single local energy minimum

- Algorithm
- Fix the receive antennas (Nr)
  - Start with Nr=1
- Identify energy optimal with *sequential probing*
- ***Prune*** the remaining settings
- Increase Nr and repeat the steps



Implementation/Evaluation

Implementation

- 802.11n commodity devices
  - 2-antenna receiver / 3-antenna AP
  - Static/mobile, TCP/UDP, various RAs
- Experiments
  - **Single client - AP (implementation)**
  - Large scale trace-driven simulations

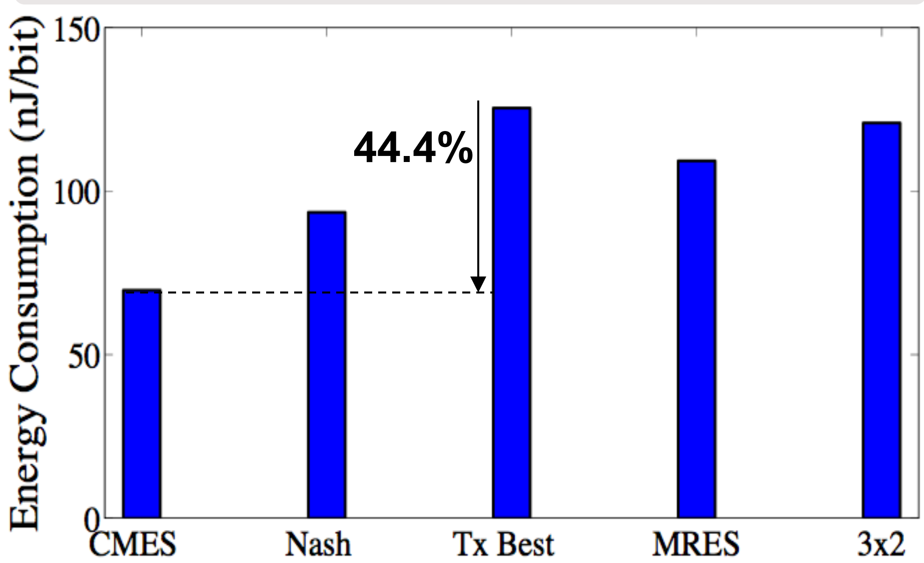
Comparing approaches

- **3x2 fixed setting**
  - Metric: **Speed**
- **MRES, Tx Best, Nash**
  - **1-side strategies**
    - MRES: receiver's energy optimal
    - Tx Best: transmitter's energy optimal
    - Nash equilibrium

Experimental results

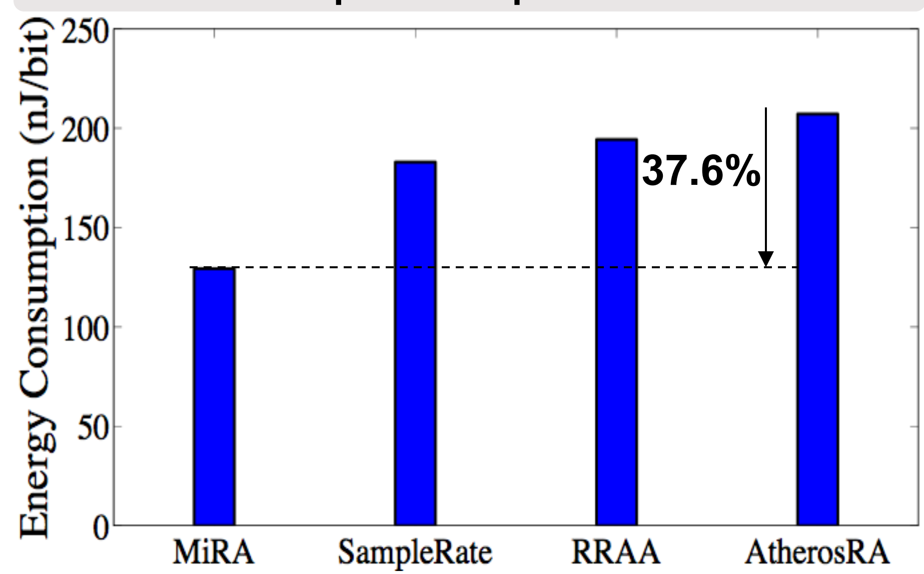
- <u>Various settings:</u> static/mobile, TCP/UDP, various practical RAs
  - Energy savings over **existing algorithms: 4.8% - 59.7%**

Time-varying channels (pedestrian mobility)



<u>CMES informed sampling</u>:
25.5-44.4% savings under mobility

Rate adaptation impact on CMES



CMES savings grow with RA's adaptability

Conclusions

- Time to rethink energy save over MIMO
  - Consider MIMO power and MIMO speed
  - Enable collaboration between transmitter and receiver
- **CMES**: collaborative, *energy optimal* antenna selection
  - Models energy as a tradeoff between transmitter-receiver power consumption and goodput
  - Excludes in advance energy hungry antenna settings

CMES: A step towards ***green*** MIMO wireless