NSRC Industry Day, 2012

Overview of Research Activities WCAN@PSU

http://labs.ee.psu.edu/labs/wcan

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Wireless Communications
& Networking Laboratory
WCAN@PSU

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WCAN@PSU

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Wireless Communications and Networking Laboratory : (since Jan.2002)

- Currently we have 10 members
  - 1 Postdoc, 7 PhD students, 1 visiting professor
- Currently we are supported by
  - National Science Foundation grants
    1. CNS-NeTS (2007)
    2. CNS-NeTS (2010)
    3. CCF (2010)
  - ARL: CTA in Network Science- Communication Networks Academic Research Center (2009)

What we do

Wireless Communications
& Networking Laboratory
WCAN@PSU

- **Mission:** Understanding the performance limits and providing fundamental design principles of ***wireless communication networks.***
- **Our Main research theme** is **optimum design of "Nth" generation** wireless networks

High capacity, secure, reliable wireless communication

Recent Awards by WCAN Students

- 2012: Kaya Tutuncuoglu (Energy Harvesting Networks): AT&T Graduate Fellowship
- 2012: Ye Tian (Interference and Cooperation in Wireless Networks): Outstanding dissertation in EE
- 2010: Xiang He (Cooperation and Information Theoretic Security in Wireless Networks): Outstanding dissertation in EE.
- 2010: Xiang He: Best Paper award in IEEE ICC

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Research Areas

- Wireless Communications
- Wireless Networks
- Information Theory
- Network Science

Current focus

- Wireless networks with Energy Harvesting Nodes
- Interference management for Multi-tier cellular networks with Femtocells
- **Security versus capacity trade-off** in multiuser systems; wireless ad hoc networks
- Information Content Capacity of Networks; quality-of-information aware networking

Green Wireless Networks

- Wireless networking with nodes harvesting energy to operate.
- Applicable to sensor networks and (in the future) wireless ad hoc networks.
- Our goal: New design paradigm and insights

- Sponsor: NSF via CNS-NeTS

Motivation

- **Wireless networking with energy harvesting nodes:**
  - Green, self-sufficient nodes,
  - Extended network lifetime, "RECHARGEABLE NW"
  - Smaller nodes with smaller batteries.
- **Challenge:**

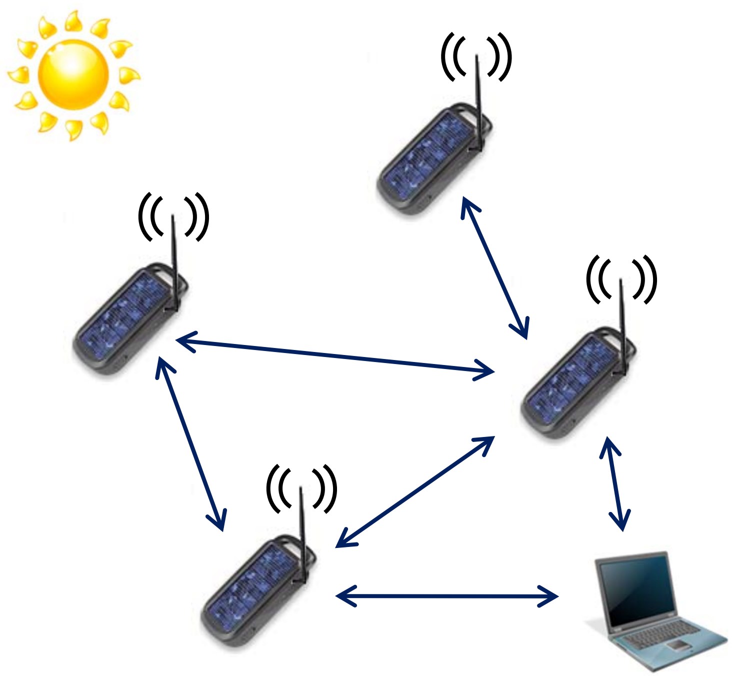
  An altogether new network design paradigm conditioned on energy availability.

Energy Harvesting

- Conventional energy supply requires:
  - Electrical wiring
  - Battery replacement
- **Energy Harvesting:**
  - Generating electricity from surrounding environment
  - light, vibration, heat, radio waves…

Some Applications

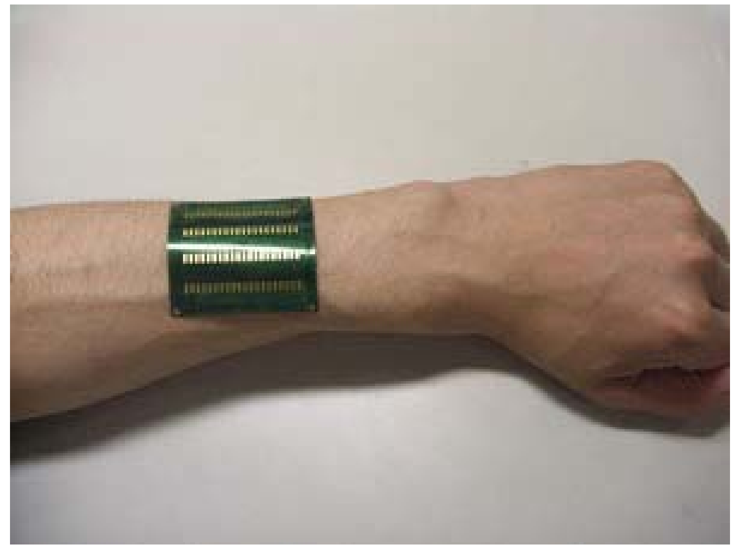
Wireless sensor networks

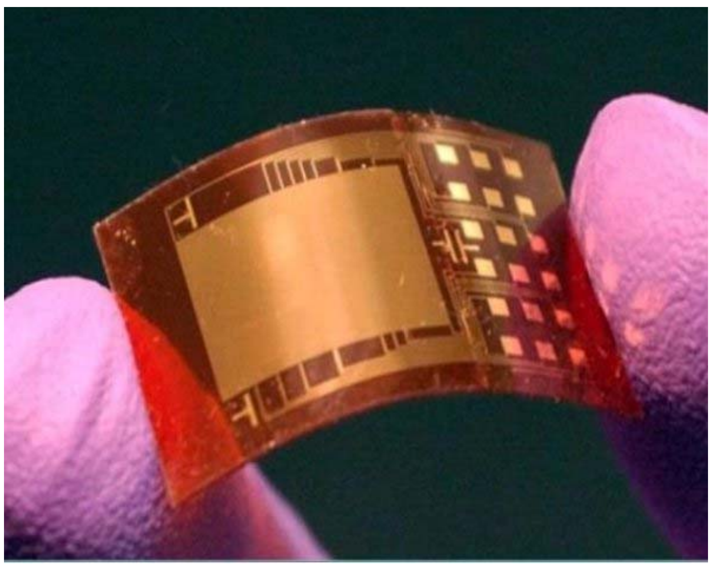


Green communications

Energy Harvesting

- Fujitsu's hybrid device utilizing **heat or light.**





- Nanogenerators built at Georgia Tech, utilizing **strain**

Image Credits:
(above) http://www.fujitsu.com/global/news/pr/archives/month/2010/20101209-01.html
(below) http://www.zeitnews.org/nanotechnology/squeeze-power-first-practical-nanogenerator-developed.html

Energy Harvesting

- Various practical applications

Image Credits:
(left) http://inhabitat.com/shoe-generator-harvests-power-from-walking/
(right) http://www.wafermaneuver.com/nick/energyharvesting.html

Motivation

- **New Wireless Network Design Challenge:**

  A **set of energy feasibility constraints** based on harvests govern the communication resources.

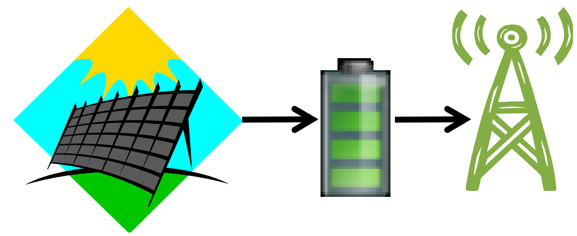
- **Design question:**

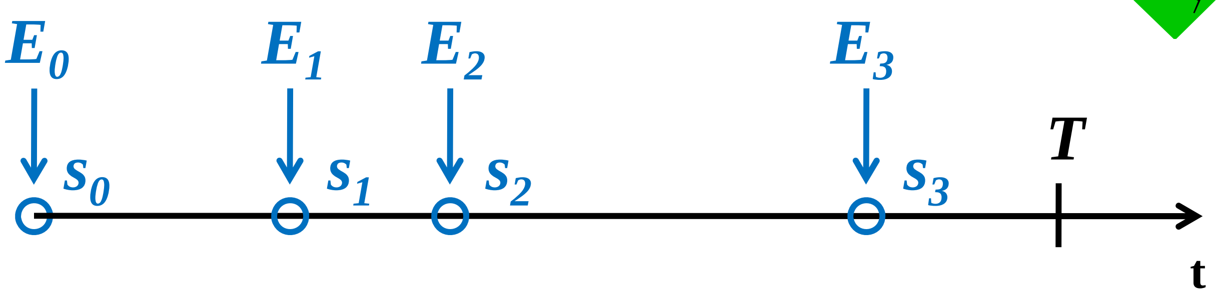
  When and at what rate/power should a "rechargeable" (energy harvesting) node transmit?

- **Optimality? Throughput; Delivery Delay**

System Model

- Energy arrivals of energy E_i at times s_i





- Energy stored in a device with capacity $E_{\max}$,
- Design parameter: **power** $\rightarrow$ **rate** $r(p)$.

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Energy Constraints

(Energy arrivals of E_i at times s_i)

- **Battery Capacity:** $\sum_{k=0}^{n-1} E_k - \int_0^{t'} p(t)dt \le E_{\max} \qquad s_{n-1} \le t' \le s_n$
- **Energy Causality:** $\sum_{k=0}^{n-1} E_k - \int_0^{t'} p(t)dt \ge 0 \qquad s_{n-1} \le t' \le s_n$

- **Set of energy-feasible power allocations**

$$\mathfrak{P} = \left\{ p(t) \,\middle|\, 0 \le \sum_{k=0}^{n-1} E_k - \int_0^{t'} p(t)dt \le E_{\max}, \forall n > 0, s_{n-1} \le t' \le s_n \right\}$$

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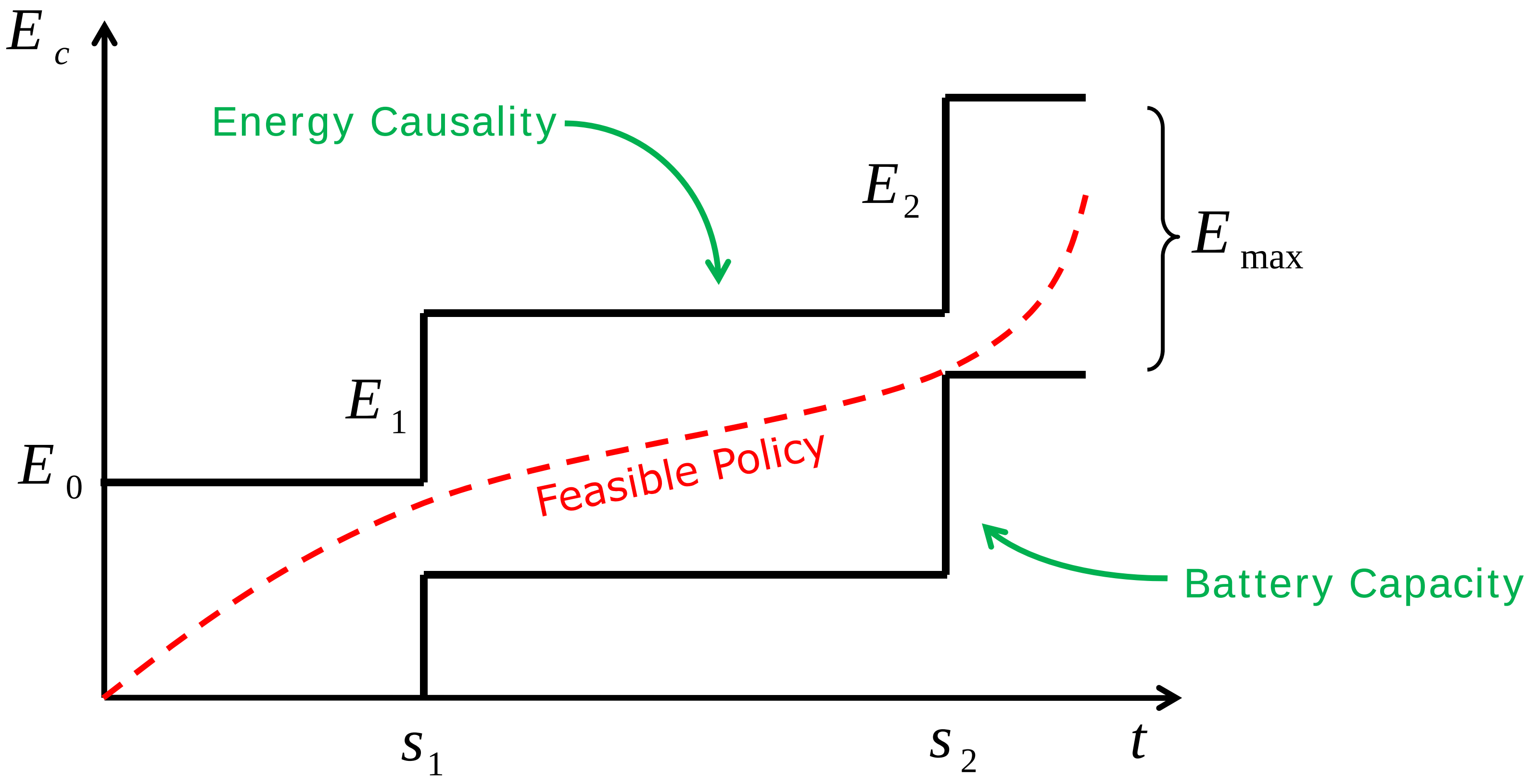
Energy “Tunnel”



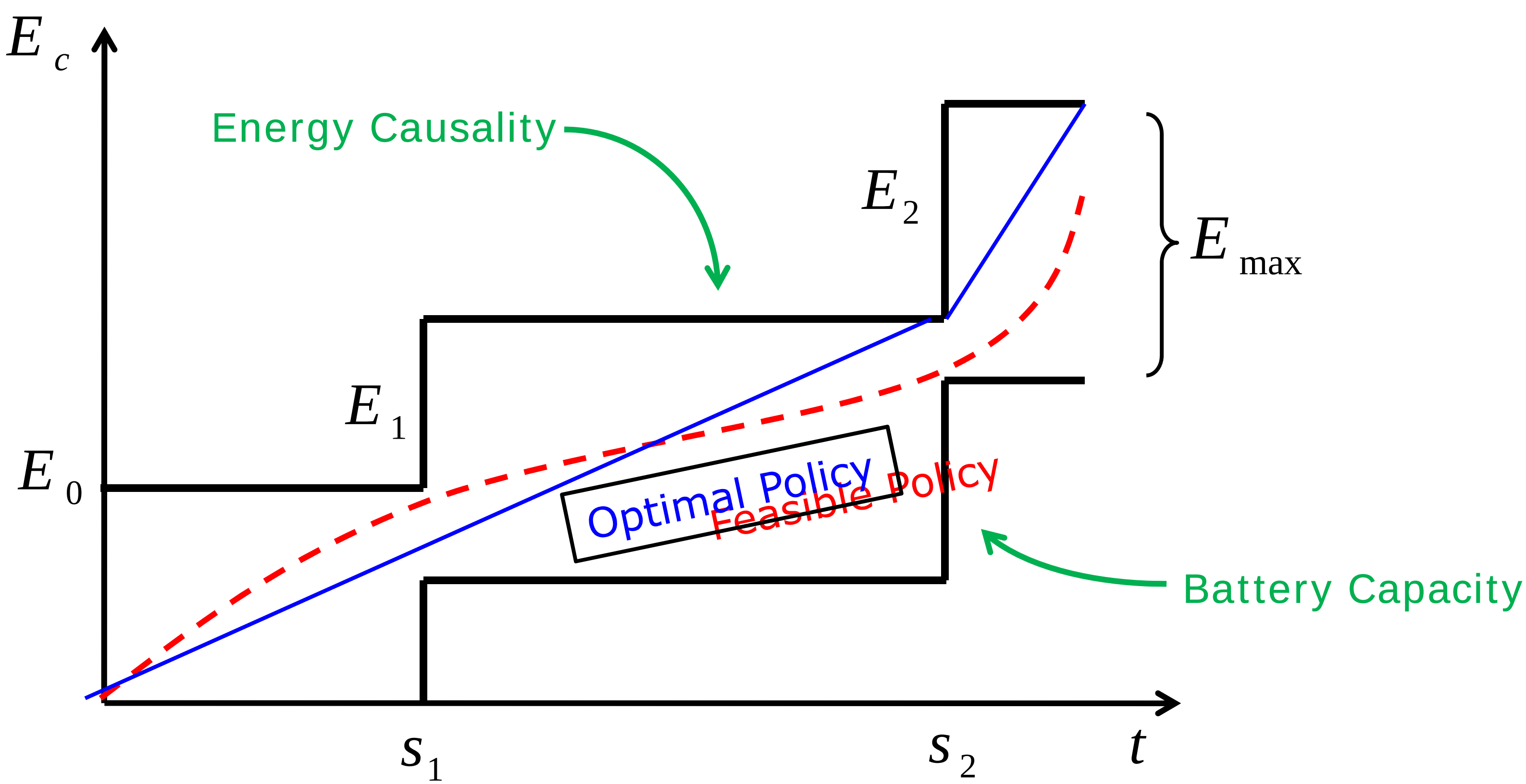
Short-Term Throughput Maximization Problem

- Maximize total number of transmitted bits by deadline **T**

$$\max_{p(t)} \int_0^T r(p(t))dt, \quad s.t. \quad p(t) \in \mathfrak{P}$$

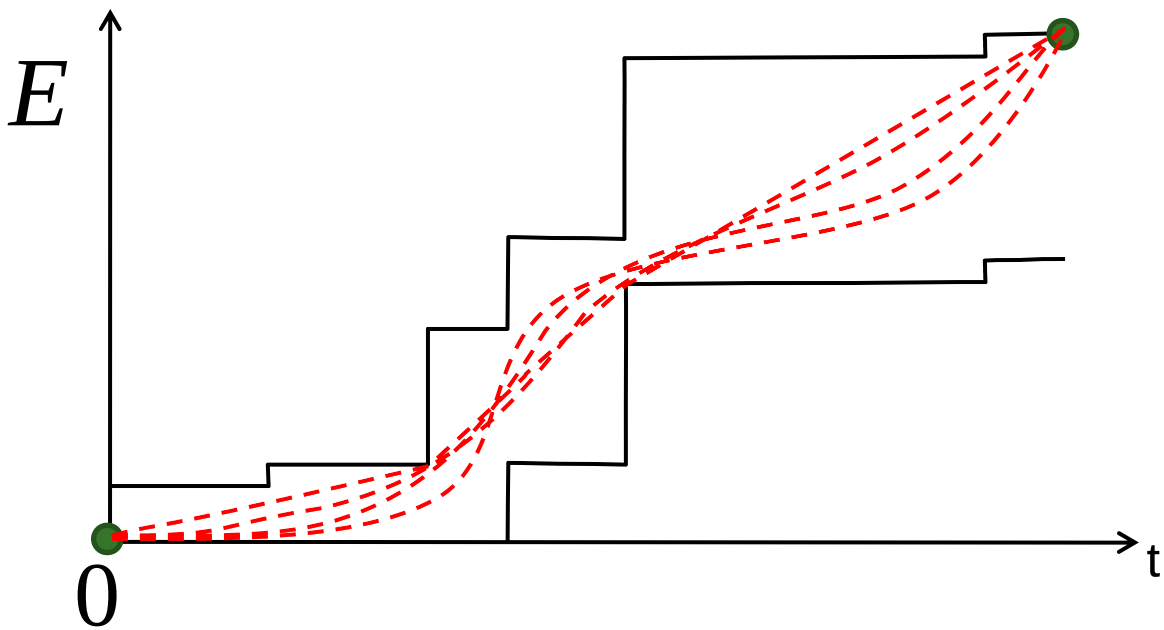
$$\mathfrak{P} = \left\{ p(t) \,\middle|\, 0 \le \sum_{k=0}^{n-1} E_k - \int_0^{t'} p(t)dt \le E_{\max}, \forall n > 0, s_{n-1} \le t' \le s_n \right\}$$

Energy "Tunnel"



Shortest Path Interpretation

- **Property 1:** Constant power is better than any other alternative
- **Shortest path** between two points is a line (constant slope)



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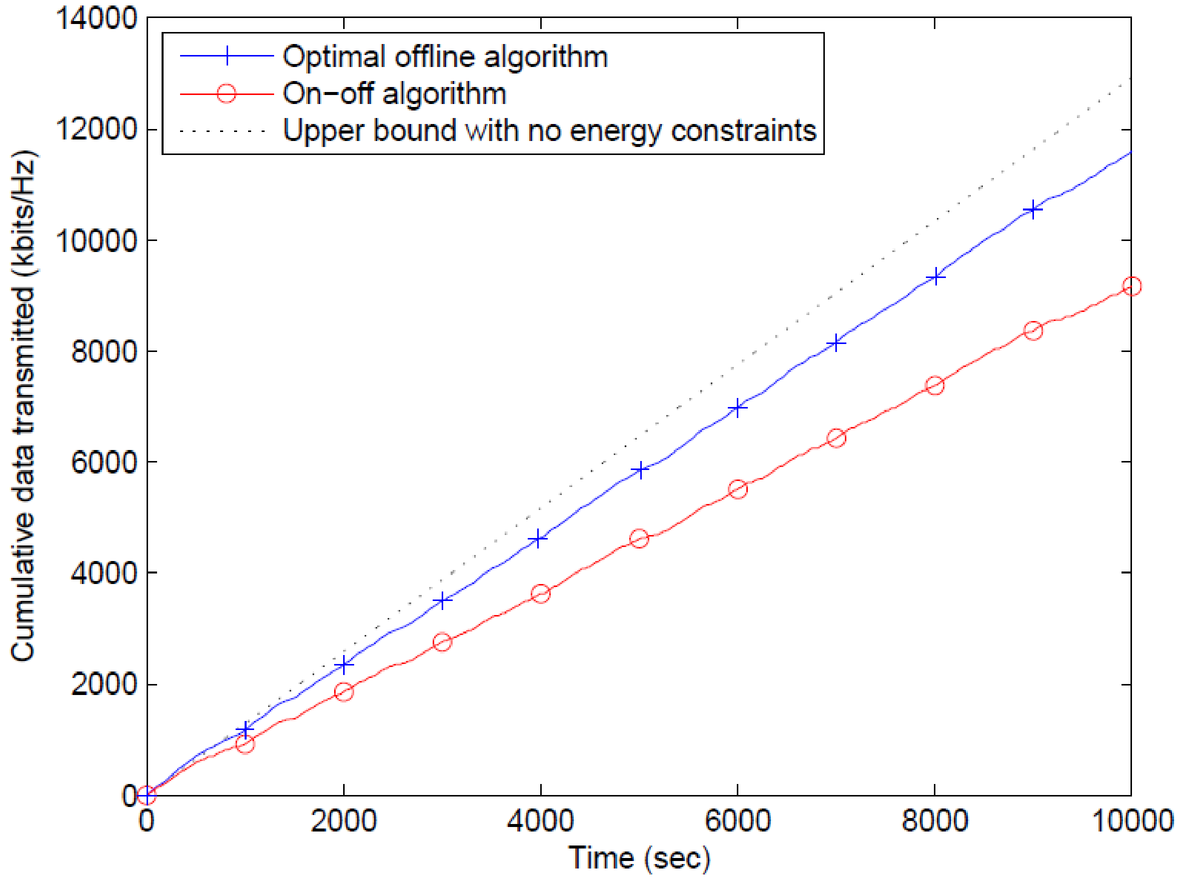
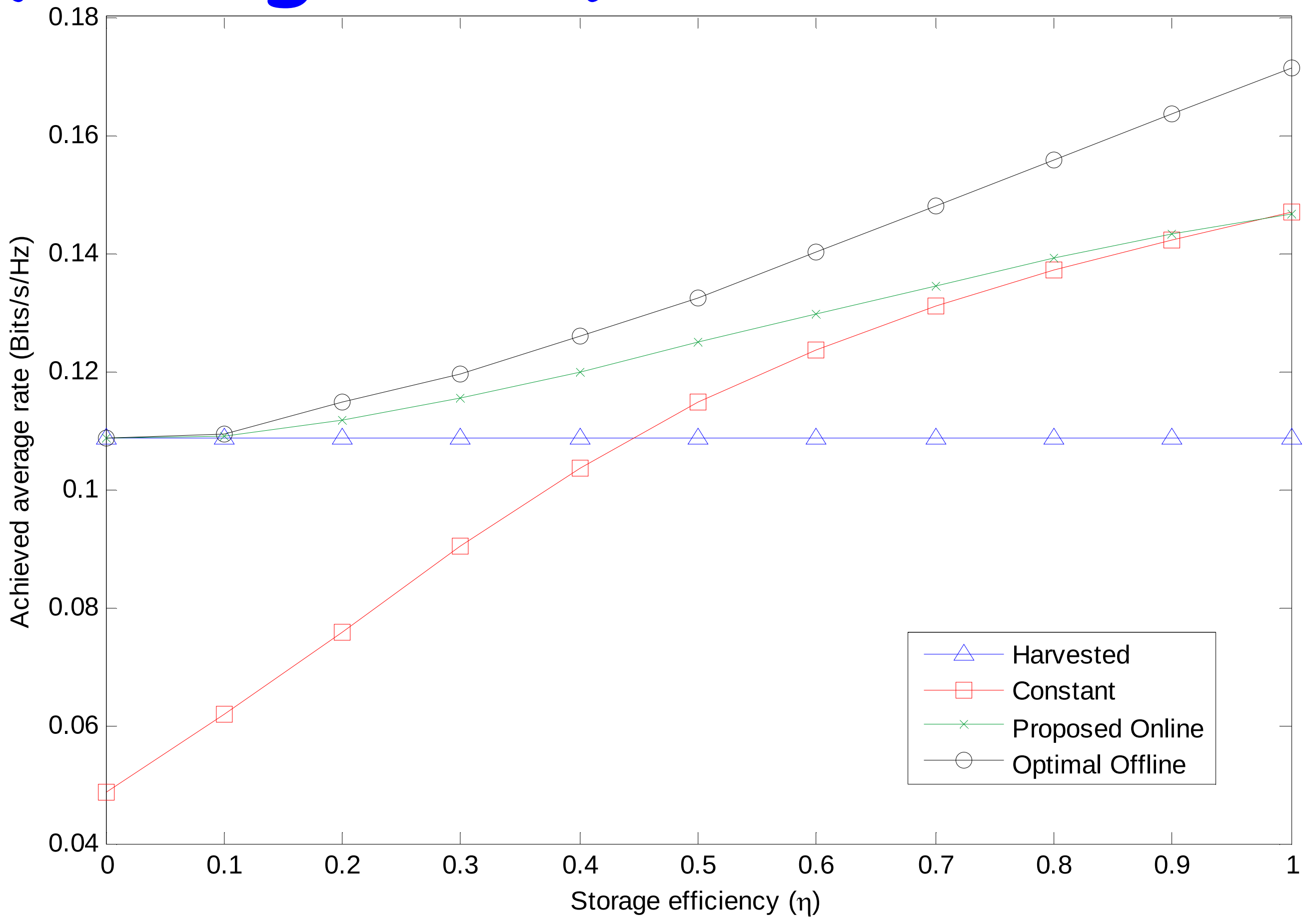
Simulation results



Simulation Results (storage loss)



Status

Many open problems related to all layers of the network design.

- Transmission scheduling
- Signal processing/PHY design
- MAC protocol design
- Channel capacity
- …

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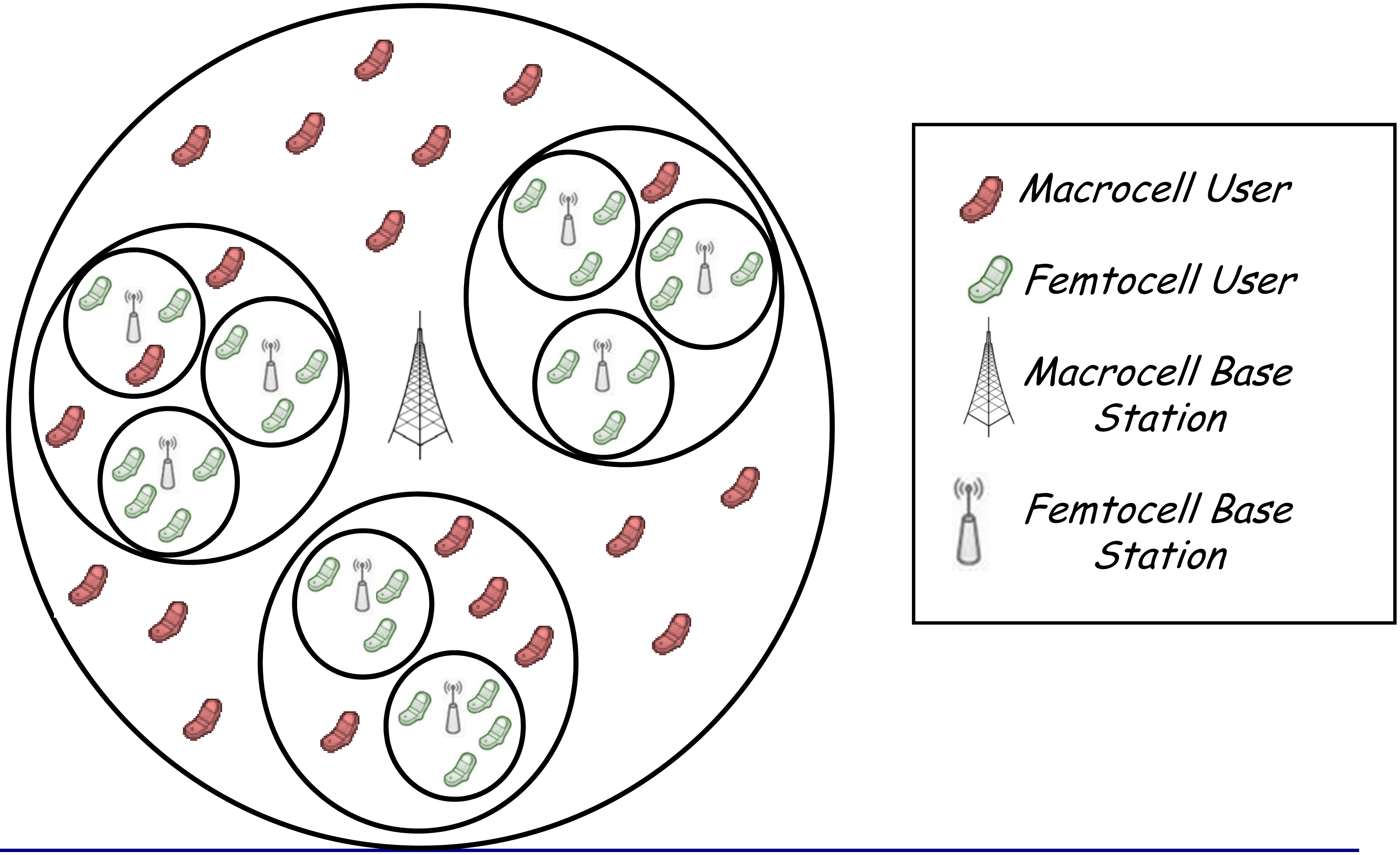
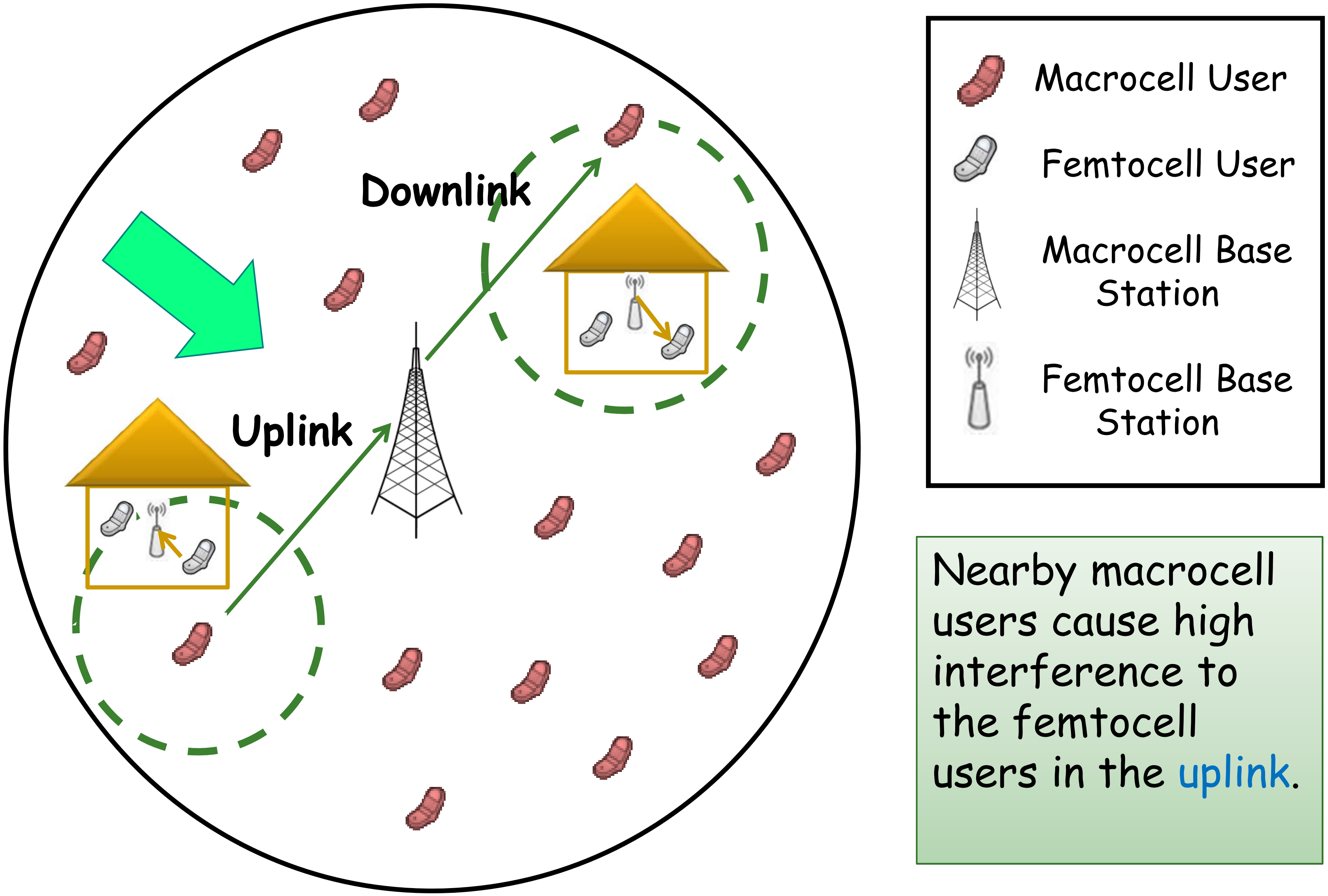
Interference Management for Femtocell and Macrocell Networks



Femtocells and Macrocells

- Various models of resource management (open access, closed)
- Our model:
  - Two-tier system with different coverage radii
  - Two co-existing networks from the same provider
  - No prior resource partition
  - Each tier serves its own "users"

Sources of Interference

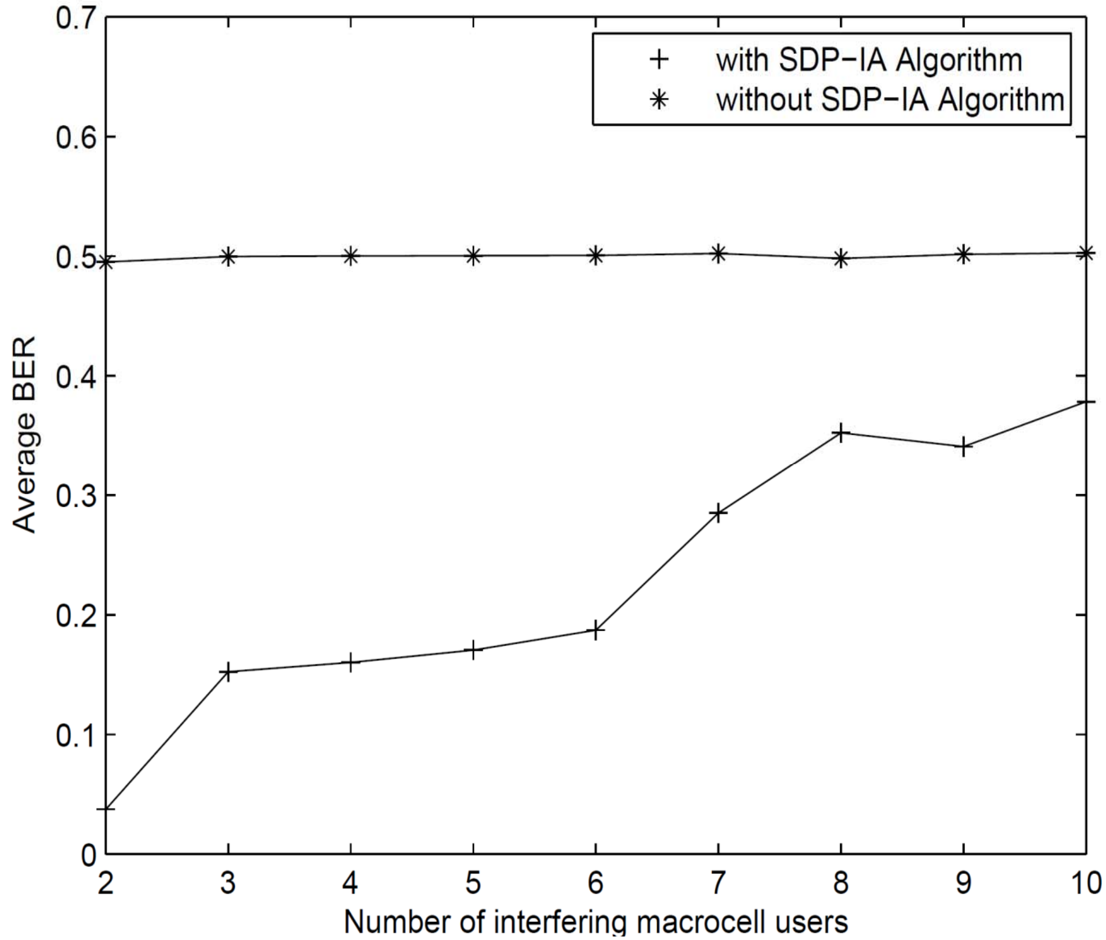


Nearby macrocell users cause high interference to the femtocell users in the uplink.

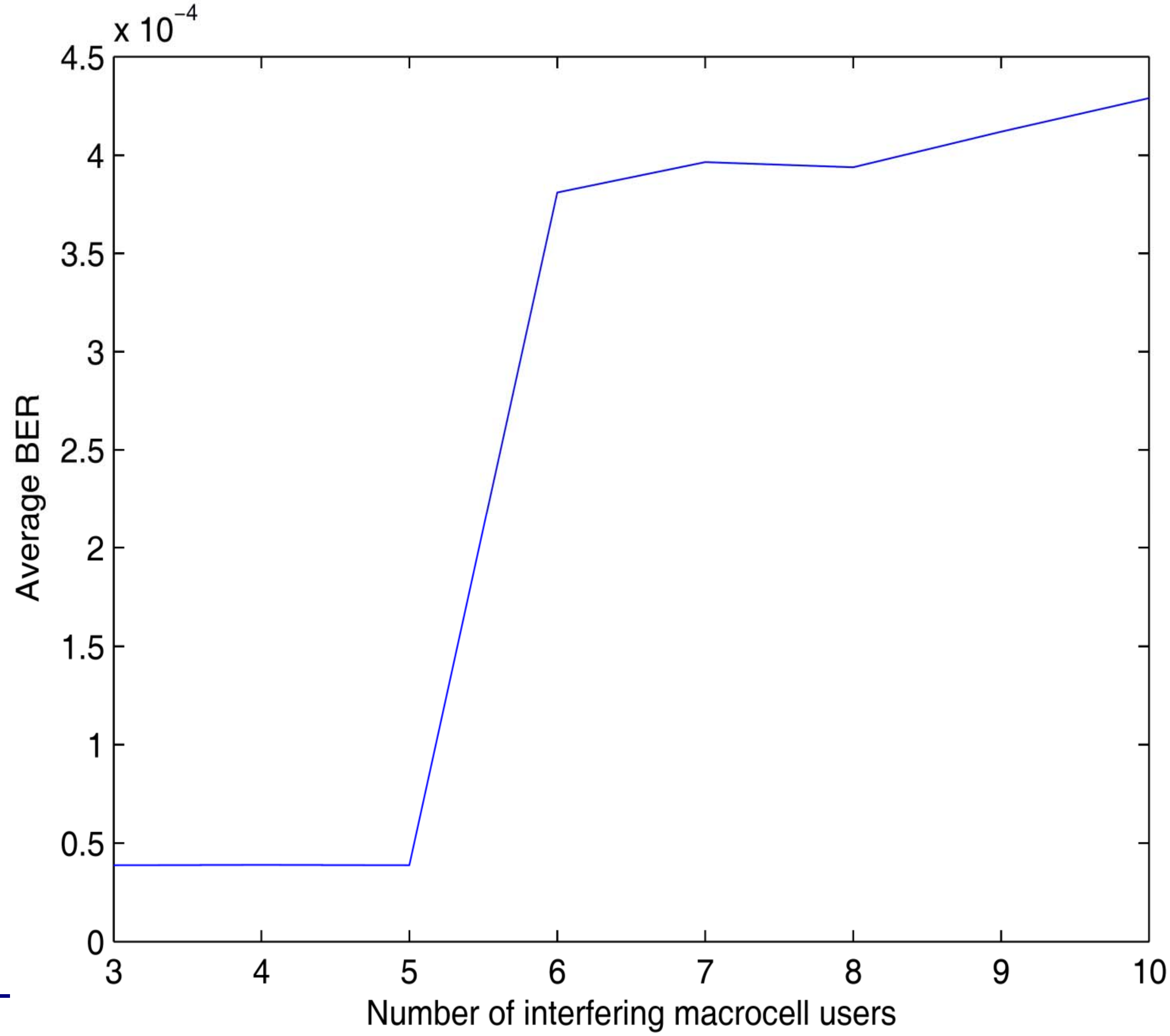
Goal: Effective Uplink IM

- Facilitate a happy medium for BOTH femtocell and macrocell users.
- Mitigate (dominant) uplink macrocell interference at Femtocell Base Stations (FBS).
- Macrocell users (MU) performance should not suffer.
- Interference alignment(IA) in a two tier system: Aligns the received interference from MU at multiple FBSs simultaneously, while making sure the MU are received properly at their base station (MBS).

Average BER of femtocell users



Average BER of Femtocell users



Secure Wireless Communications (NSF 2005, 2007, 2010)

- **Wireless security concerns currently handled by upper layers of the protocol stack ➔ top-to-bottom approach.**
- **Can we design a secure wireless system from PHY up?**
- **Information theoretic security**
- **Tool: Network Information Theory**
- **Complete immunity to eavesdropping nodes**
- **Challenging design problems arise when we consider non-point-to-point communication systems with security.**

New Design Insights

- We can design transmission strategies that *guarantee* confidentiality of transmitted information in the presence of computationally unbounded passive adversaries.
- These strategies are useful also in enabling cooperation with network nodes of lower security clearance.
- Interference when intentionally introduced to hurt adversaries is a good thing!
- Untrusted (but functionally trusted) entities can participate in the network and be helpful.
- Designing secure wireless (ad hoc, sensor) networks is possible at their foundation, i.e., PHY layer.
- This approach can replace or strengthen key-based approaches.

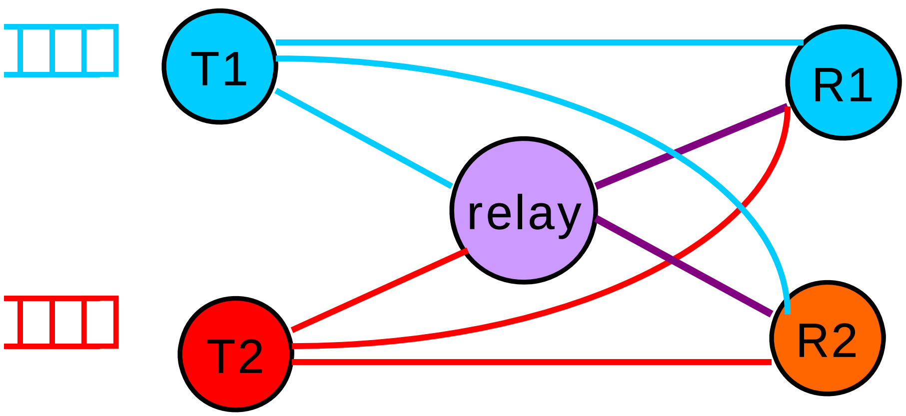
A New Information Theory for Mobile Ad Hoc Networks (ITMANET 2006-2012)

- **With 12 colleagues from UT,UMN,ND,NW,USC,UC,MIT,Drexel**
- **Classical information theoretic tools are insufficient to address the ultimate performance limits of mobile ad hoc networks.**
- **There is no comprehensive theory to capture the dynamic nature of mobile ad hoc networks.**
- **Many rich sub-problems exist to address the statistical nature of the traffic, quantifying the impact of overhead and security.**

✓ ***What is the ultimate capacity of a MANET?***

New Design Insights

- New network building blocks considering interference and cooperation:



- New network control policies, rate allocation and scheduling, ensuring reliable communication and stable queues.
- New design techniques ensuring confidentiality of information.

Networks of the future (ARL: NS-CTA 2009)

- Network Science CTA Communication Networks Academic Research Center
- New network design paradigms
- Collaborative alliance with ARL and three other centers focusing on information networks, social and cognitive networks, and integration of all networks.
- Our contribution: Quality-of-information aware nw design, operational information content capacity

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