



THE WIRELESS LINK PERSPECTIVE IN WIRELESS NETWORKING

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WIRELESS NETWORKING



- “Maturing” (catalytic effect of MAC)
- Diverse (from cellular to sensors)
- Growing (in \$ and in interest)
- Rich (truly new intellectual and design problems)
- Confusing (if not chaotic)
- Success Stories
- Areas of Challenge

WHY “CONFUSING”?

- DOES NOT QUITE “FIT” THE WIRELINE NETWORK PARADIGM
 - “Link” is a relative (or “soft”) concept
 - MAC is a key concept
 - Energy is important (all of a sudden)
 - Mobility
 - Relationship to Infrastructure
 - Application Drivers (e.g. sensors, military, etc.)
- COMBINES (INSEPARABLY) MANY DISCIPLINES

THE “CULPRIT”

- THE WIRELESS LINK -
 - Breaks down the traditional concept of topology
 - Strengthens the cross-layer coupling
 - Brings in a different culture of thinking

WHAT IS A LINK?



$$SINR > \gamma$$

*SINR: RF transmit power, antennas, other users,
channel, rate*

*γ : detector structure, mod/demod, waveforms, cod/dec,
BER target*

*Underlined quantities make the notion of a link readily
controllable*

CONSEQUENCES

- CLEARLY NO FIXED TOPOLOGY (even without mobility)
- CROSS-LAYER COUPLING
 - power ↔ energy consumption ↔ higher & lower layers
 - other users ↔ MAC
 - rate ↔ throughput ↔ higher & lower layers
 - BER ↔ new QoS measure ↔ application layer
- DIFFERENT CULTURE
 - Rich Theory of Communication
 - Rigorous Analysis, Precise Modeling
 - Complex Details

CONSEQUENCES (Con't.)

- IGNORING THE PHYSICAL LAYER LIMITS THE MEANINGFULNESS OF NETWORKING ANALYSIS AND DESIGN
- TAKING THE PHYSICAL LAYER INTO ACCOUNT CAN BE DONE SELECTIVELY (but carefully) AND YIELD USEFUL RESULTS

- MULTIPLE ACCESS (from ALOHA to elaborate reservation and scheduling schemes)
 - power control
 - dynamic channel allocation
 - elaborate hand-offs & mobility tracking
 - interfacing to the IP network
 - made cellular telephony & systems the miracle of the '90's
 - enabled WLAN's (802-11, Bluetooth, etc.)
- ROUTING (multitude of algorithms)
 - on demand
 - distributed
 - link state
 - location/direction-based
 - elaborate metrics
 - “all above average”

- EMERGENCE OF FUNDAMENTAL PRINCIPLES
 - “capacity” of ad-hoc networks
 - exploitation of apparent impediments
 - mobility
 - fading (multi-user diversity)
 - understanding energy implications
 - capturing layer interactions

AREAS OF CHALLENGE

- LACK OF THEORY
 - ultimate limitations: elusive
 - fragmentation of research
 - heavy reliance on heuristics
 - auto “magic” protocols
 - shortage of fundamental research
- APPLICATION DEPENDENCE
 - interfacing to the IP network (3G)
 - sensor networks vs. digital battlefield (40g)
 - home network vs. voice telephony
 - browsing vs. symmetric

AREAS OF CHALLENGE (Con't.)

- **SIZE AND SCALABILITY**
 - Complexity (often combinatorial)
 - Performance (often unacceptable)
- **RESOURCES AND ECONOMICS**
 - Precious spectrum instead of cheap fiber
 - Mobility
 - Public spoiled by the internet and cellular voice



THE ROLE OF THE WIRELESS LINK (examples)



- RATE AS A MEANS OF CONNECTIVITY CONTROL
- TRADE-OFF BETWEEN ENERGY FOR PROCESSING AND FOR TRANSMISSION
- EFFECT OF RF-POWER ON ROUTING AND MULTICASTING AND ON COUPLING WITH MAC
- REVERSAL OF TRADITIONAL THINKING REGARDING CAPTURE
- PRINCIPLE OF OPPORTUNISTIC SIGNALING
- PULSING OF BATTERIES

CONNECTIVITY CONTROL VIA RATE

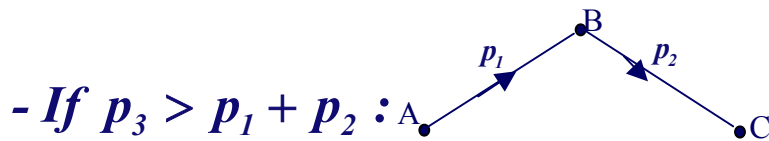
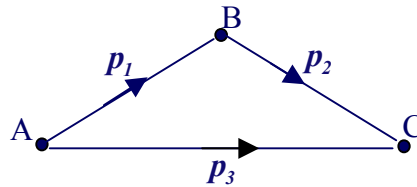
- PREFERABLE TO POWER BECAUSE IT DOES NOT AFFECT INTERFERENCE (non-invasive)
- LOWERING THE RATE PERMITS THE PACKAGING OF MORE ENERGY PER SYMBOL ($\text{SINR} > \gamma$)
- SO, A FALTERING LINK CAN BECOME MORE RELIABLE (elasticity)
- A PREVIOUSLY NON EXISTENT LINK CAN BE CREATED
- RATE REDUCTION LOWERS THROUGHPUT OR INCREASES DELAY OR DISTORTS THE SIGNAL
- CAN BE DONE EITHER AT THE TRANSMITTER OR THE RECEIVER

PROCESSING vs. TRANSMISSION ENERGY

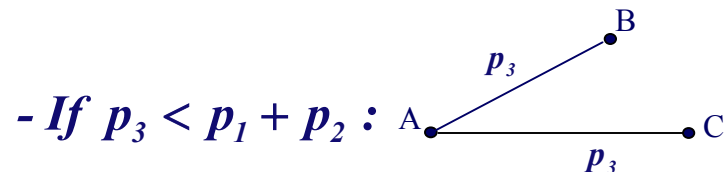
- SAY R bits/s SUFFICE TO DESCRIBE A SIGNAL AND $BER = p$ PERMITS SATISFACTORY RECREATION OF THE SIGNAL
- IF R IS REDUCED TO $R/2$ (via additional compression) THE RF TRANSMISSION ENERGY IS ALSO HALVED
- DISTORTION AT THE RECEIVER APPARENTLY INCREASES
- BUT p CAN BE REDUCED AT THE SAME TIME (the fewer bits are received more reliably)
- OVERALL DISTORTION MAY OR MAY NOT INCREASE
- OVERALL ENERGY CONSUMPTION MAY OR MAY NOT DECREASE
- NOVEL TRADE-OFF (Note: coupling of link layer and presentation layer)

RF-POWER AND ROUTING/MULTICASTING

- POWER NEEDED TO REACH A NODE AT DISTANCE r
 $\sim r^\alpha, \quad 2 < \alpha < 4$
- WHISPERING BETTER THAN YELLING (for unicast)
- TRADE-OFF UNCLEAR FOR MULTICASTING
- WIRELESS MULTICAST ADVANTAGE AND PRINCIPLE OF INCREMENTAL POWER



at cost $p_1 + p_2$



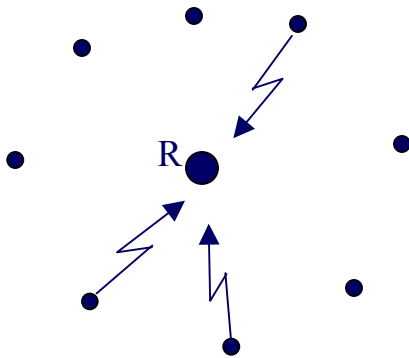
at cost p_3

(Con't.)

- SEVERAL ALGORITHMS FOR TREE CONSTRUCTION
- SEVERAL ALGORITHMS FOR ACTUAL SOURCE-BASED SESSION MULTICASTING (no mobility and centralized) WITH CONSTRAINED RESOURCES
- NEW METRICS FOR DATA ROUTING THAT CAPTURE COMMUNICATION PERFORMANCE AND ENERGY CONCERNS (note: coupling the bottom three layers).

CAPTURE

TRADITIONAL THINKING: CAPTURE OCCURS WHEN ONE OF SEVERAL OVERLAPPING SIGNALS IS STRONGER (with MUD, actually, more than one signal can be successfully captured)



THUS

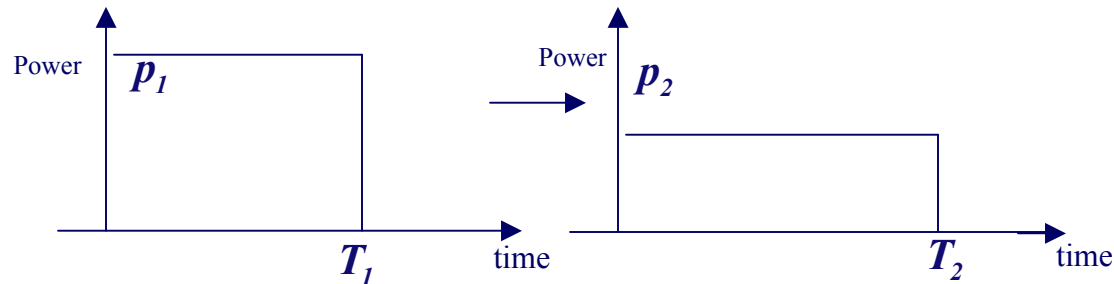
INCREASED THROUGHPUT (in a simple single-cell environment)

TRADITIONAL IDEA: TO ENSURE POWER LEVEL DIFFERENTIATION, ALL USERS SHOULD USE DIFFERENT POWER LEVELS
(anti-power-control)

CAPTURE (Con't.)

PHYSICAL LAYER THINKING: CAPTURE MEANS

$$SINR > \gamma \text{ AND}$$



$$\text{If } P_1 > P_2 \text{ then } T_1 < T_2$$

THEREFORE: Multiple power levels permit capture (to increase throughput) but also require some longer packets and hence more frequent “collisions” (that decrease throughput)

Q: WHICH WAY IS THE TRADE-OFF RESOLVED?

CAPTURE (Con't.)

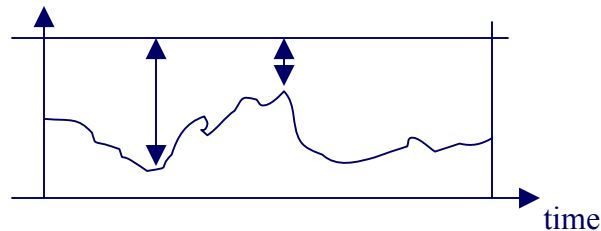
A: TRANSMIT AT MAX (hence equal) POWER

- No capture benefits
- Maximum Time Separation
(fewer collisions)

NOTE: ARGUMENT FOR ORTHOGONAL
SIGNALING (in limited setting)

OPPORTUNISTIC SIGNALING

- ORIGINS: ~'95
- PRINCIPLE: TRANSMIT MAXIMALLY WHEN CHANNEL IS BEST (waterfilling arguments)



- EXTENSION: MULTI-USER DIVERSITY ('00)
whoever has the best channel at a given time should use it exclusively

NOTE: ARGUMENT FOR ORTHOGONAL SIGNALING
(another limited setting)

Principle of Exploitation of Adversity

- Continuous Draining Reduces Total Energy Supply
- Pulsed Draining Increases Total Energy Supply

NOTE 1: Another Argument for Orthogonal Signaling (TDMA)
(in yet another limited setting)

NOTE 2: Can pulse in TDMA fashion the cells of a given battery for continuous transmission

TO WRAP UP

- THE WIRELESS LINK CHANGES THE TRADITIONAL NETWORK PARADIGM IN MULTIPLE WAYS
 - Coupling the Layers
 - “Softening” the Topology
 - Introducing Pillars of Theory
- IT MAY COMPLICATE THE NETWORK DESIGN PROBLEM
- IT MAY ALSO SIMPLIFY IT (Brings New Tools to the Arsenal)
- IT BRINGS “PHYSICAL REALITY” INTO THE “VIRTUAL” NETWORK
- CAN HELP TRANSFORM CHALLENGES TO OPPORTUNITIES

- THE “BIG BANG” OF A UNIFIED UNDERLYING THEORY MAY NEVER OCCUR
- THE FUNDAMENTAL LIMITATIONS MAY BE ILLUMINATED BY LOOKING AT ASYMPTOTIC REGIMES
- WIRELESS WILL BE PART OF OUR FUTURE
- THE FUN HAS JUST BEGUN!