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A MAC protocol for Very Low Power Ultra-Wide Band Communication

Jean-Yves Le Boudec
joint work with
Ruben Merz, Bozidar Radunovic, Joerg Widmer

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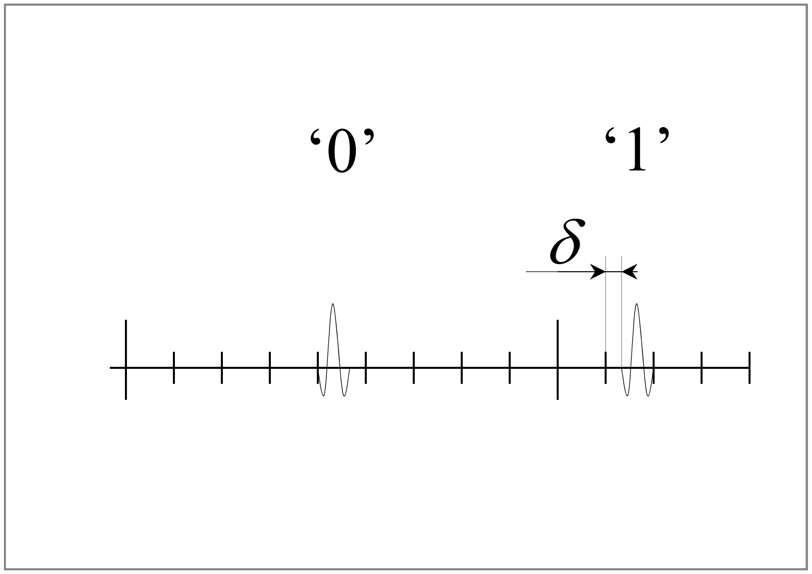
1. Goal of our research

- Design a multi-user access protocol for UWB that is
  - self-organized
  - for very low *emitted* power

2. What is Ultra Wide Band ?

- Radio Transmission Technology, very low energy in all frequency bands
- Unlicensed
- Short pulses
- Example: [WinScholtz2000] pulse position modulation



Very Low Power UWB

- UWB has the potential to use very low power
- Our focus: reduced *emitted* power
  - environmental concern
  - pervasive computing

- Our threshold : 1 microwatt emitted power

  - Maximum : 18 Mb/s for one user with line of sight
  - depends on noise and attenuation
    - 30 meters, maximum is 6 Mb/s for one user
    - in practice much less due to noise and interference

3. Our Research is: self-organized Multiple Access for UWB

- State of the art:
  - existing protocols designed for narrowband are retrofitted WiFi, TDMA (GSM), HiperLan
  - 802.15.3: UWB is just another physical layer
- This is not possible for very low power:
  - medium is shared too thinly
  - example: 6 Mb/s for all users together
  - very far from the optimal

Our Approach: Consider the Global Problem

- Accept all degrees of freedom together
  - power control
  - coding rate
  - exclusion (protocol)
- Traditional approaches in wireless LANs are based on «mutual exclusion »
  - only one source can send at a time in the channel or in a given sub-channel
  - TDMA, CSMA/CA, MACA etc.
  - used in WiFi, BlueTooth
  - interference is either below a noise threshold or is banned
- There are unexploited dimensions
  - interference can often be allowed
    - example CA/CDMA [Muqattash-Krunz2003]
  - coding can be *adaptive*
    - adapt to channel variation at the time scale of a packet, including interference

Searching For Optimal Design

- Model a general wireless ad-hoc network with
  - variable coding rate
  - exclusion (i.e. scheduling in the time domain)
  - arbitrary, possibly multipath, routing
  - protocol overhead of exclusion not accounted for
- Numerically solve for the allocation of powers and schedules that achieves proportional fairness
  - other objectives are known to be buggy [Radunovic Infocom2004]
  - random and symmetric networks up to 60 nodes

$$U = \max_{R \in \mathcal{R}, \mathbf{f} \in \mathcal{F}(R)} \sum_{i=1}^{I} \log(f_i)$$

$$\begin{aligned}
f_i &= f_i^{nr}(1 - C_r)(1 - q)^{r_i - 1} \\
\mathbf{f}^{nr} &\leq R\bar{\mathbf{x}} \\
\bar{\mathbf{x}} &= \textstyle\sum_{n=1}^{L+1} \alpha_n \mathbf{x}^n \\
\mathbf{x}_l^n &= K\,\mathbf{SNR}_l(\mathbf{p}^n) \\
\mathbf{SNR}_l(\mathbf{p}^n) &= \frac{\mathbf{p}_l^n h_{ll}}{N + \sum_{k \neq l} \mathbf{p}_k^n h_{kl}} \\
1 &= \textstyle\sum_{n=1}^{L+1} \alpha_n \\
\mathbf{p}_l^n &\leq P_l^{MAX}
\end{aligned}$$

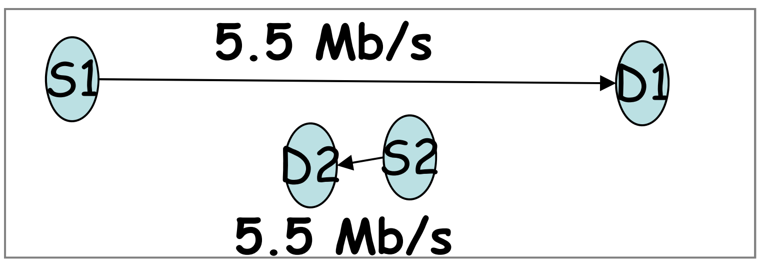
Finding 1: On-Off Power

- Optimal power control is On-Off
- Any other policy is not optimal
- Contrast with CDMA design

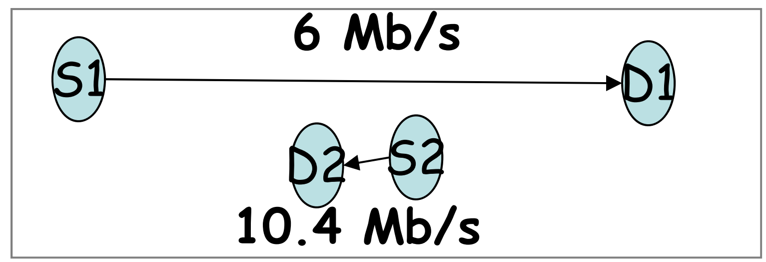
Finding 2:
Mutual Exclusion is not Optimal

Nominal rate 11 Mb/s

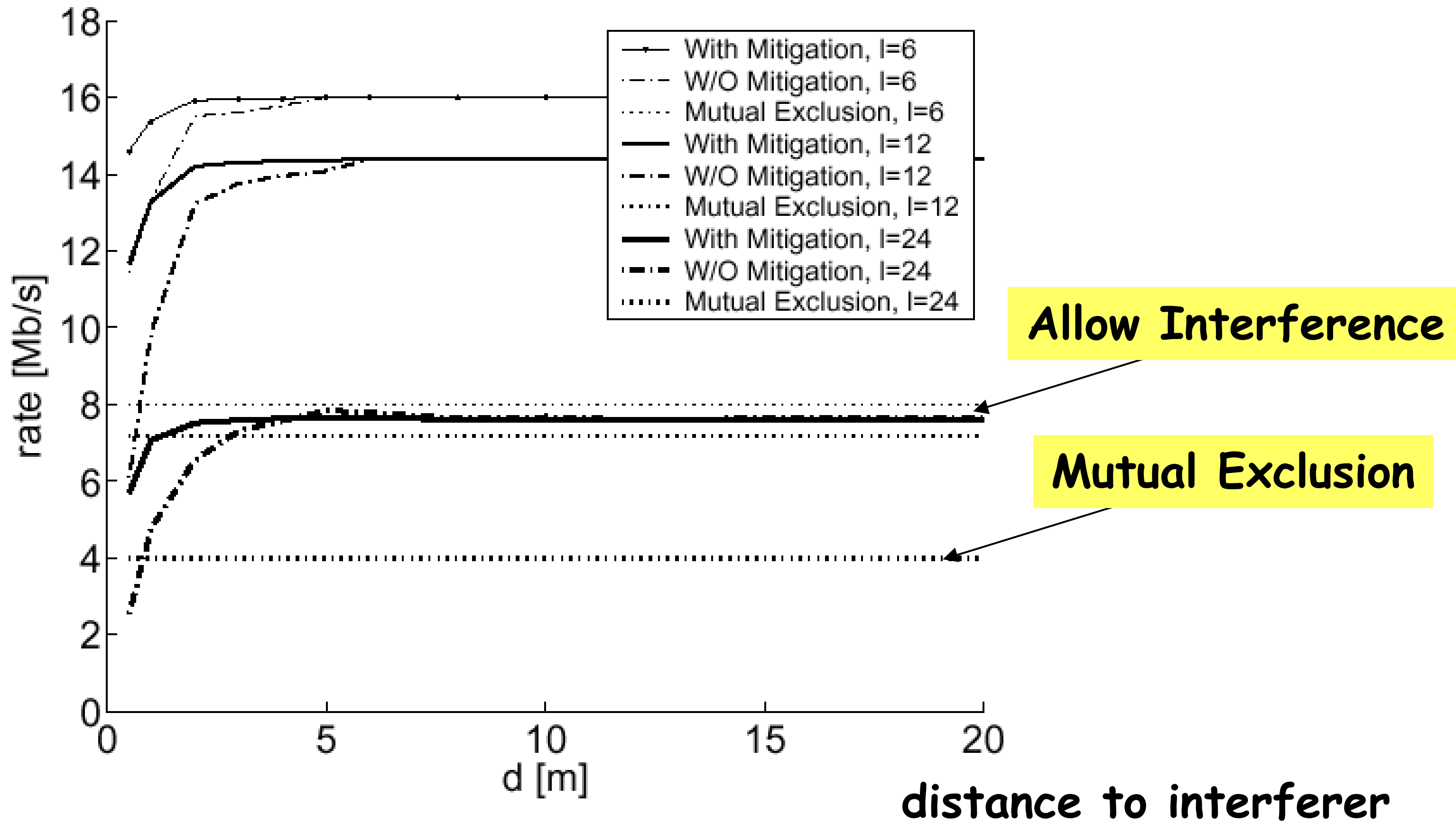
Mutual Exclusion

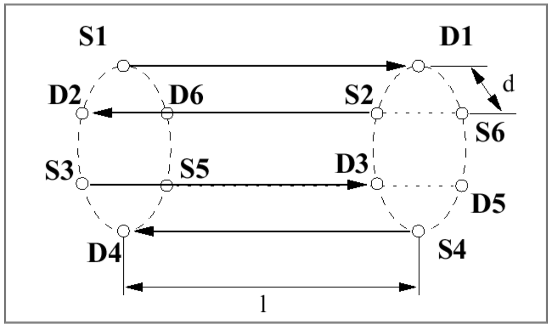


Allow Interference



Mutual Exclusion is not Optimal





What this tells us

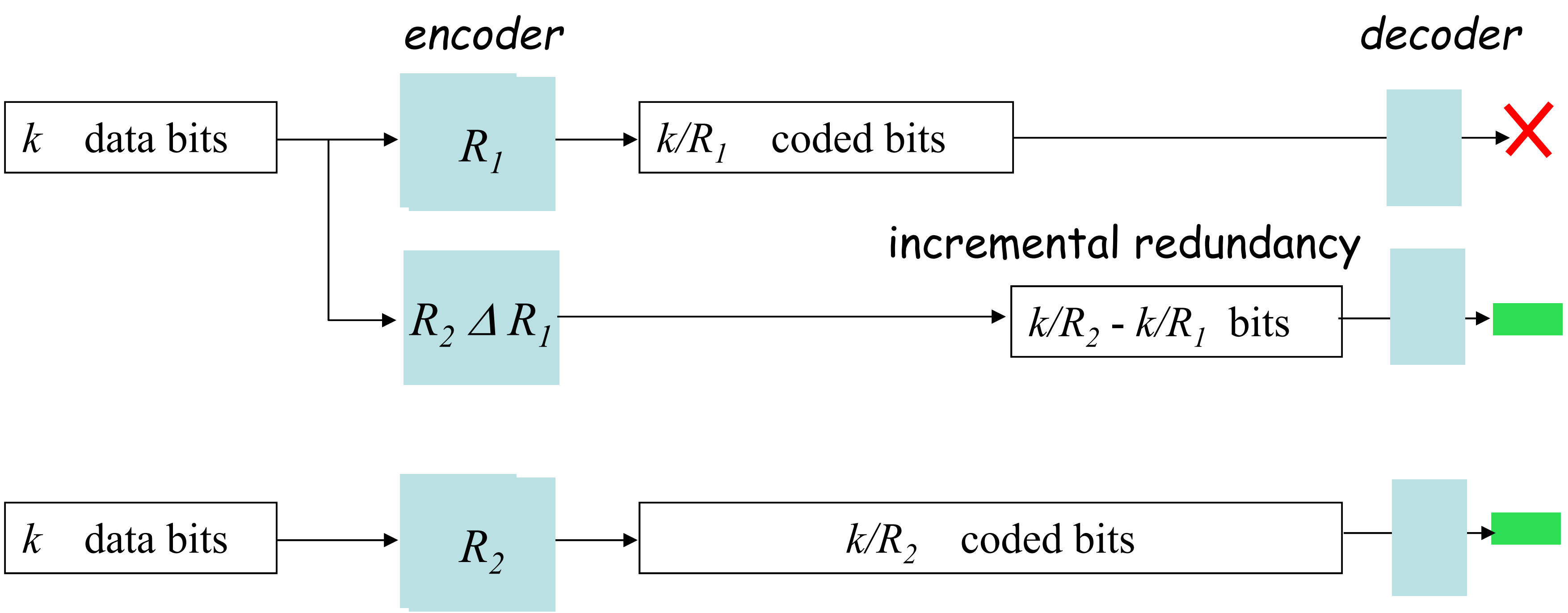
- Suggested MAC design for very low power with interference mitigation
  - 1. allow interference,
  - 2. no power control
  - 3. adapt the code rate to the level of interference

4. Our Concrete Proposal
Dynamic Channel Coding MAC Protocol

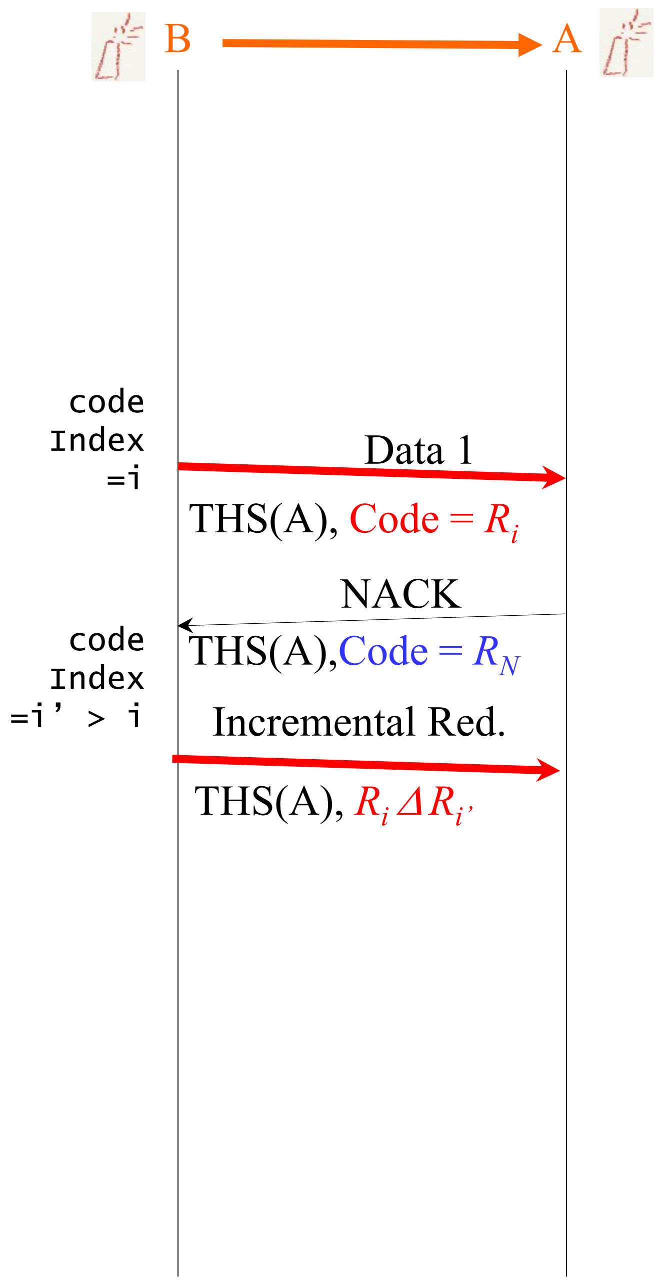
- Based on our theretical results
  - allow interference
  - adapt code
- It remains to solve
  - the « Private MAC Problem »:
    several sources send to same destination
  - carrier sensing not possible

We Use Incremental Redundancy Codes

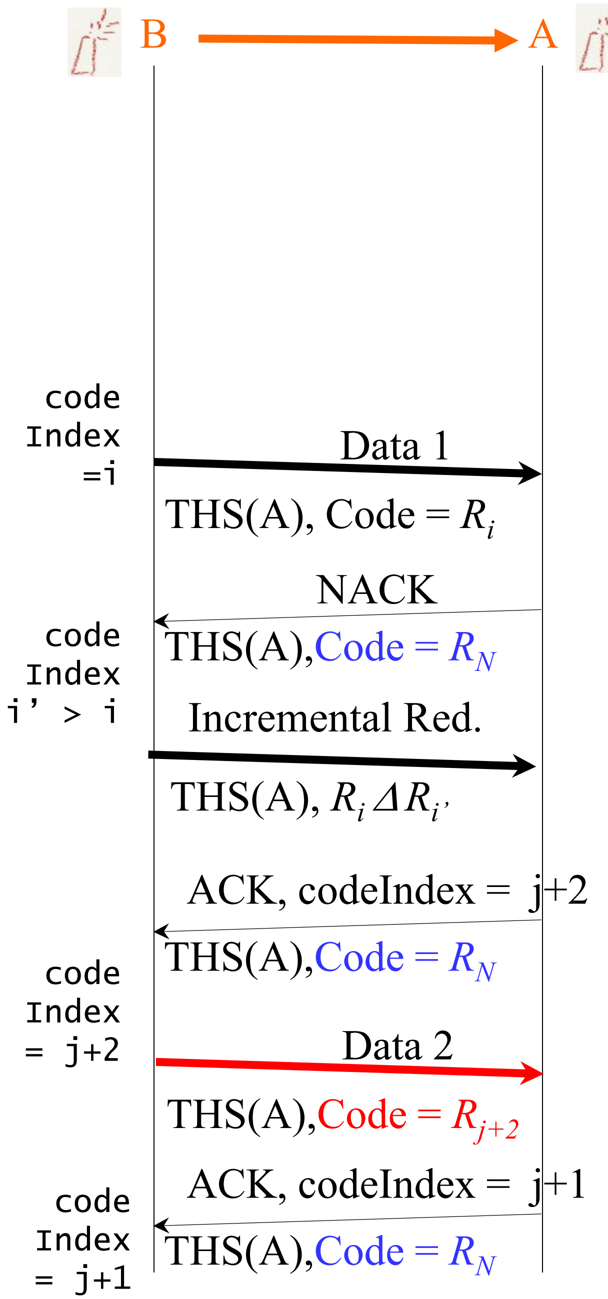
- A family of codes that cover rates from 1 to 1/10
- No penalty for sending incremental bits later



Dynamic Channel Coding



- Goal: use the most economical code
  - set for every packet
  - avoid hard failure
- Source keeps estimate of code to use in `codeIndex` (say `i`)
- If destination cannot decode (*hard failure*)
  - NACK sent to source
  - source increments `codeIndex` so that rate is divided by 2 until min rate
  - source sends incremental redundancy



- A safety margin of 2 indices is kept
- If destination can decode, it can also compute the most economical code index *j* that would have been sufficient
  - returns j+2 in ACK
  - (gradual increase):

    if j+2 > i source does codeindex=j+2

    else codeindex=i-1

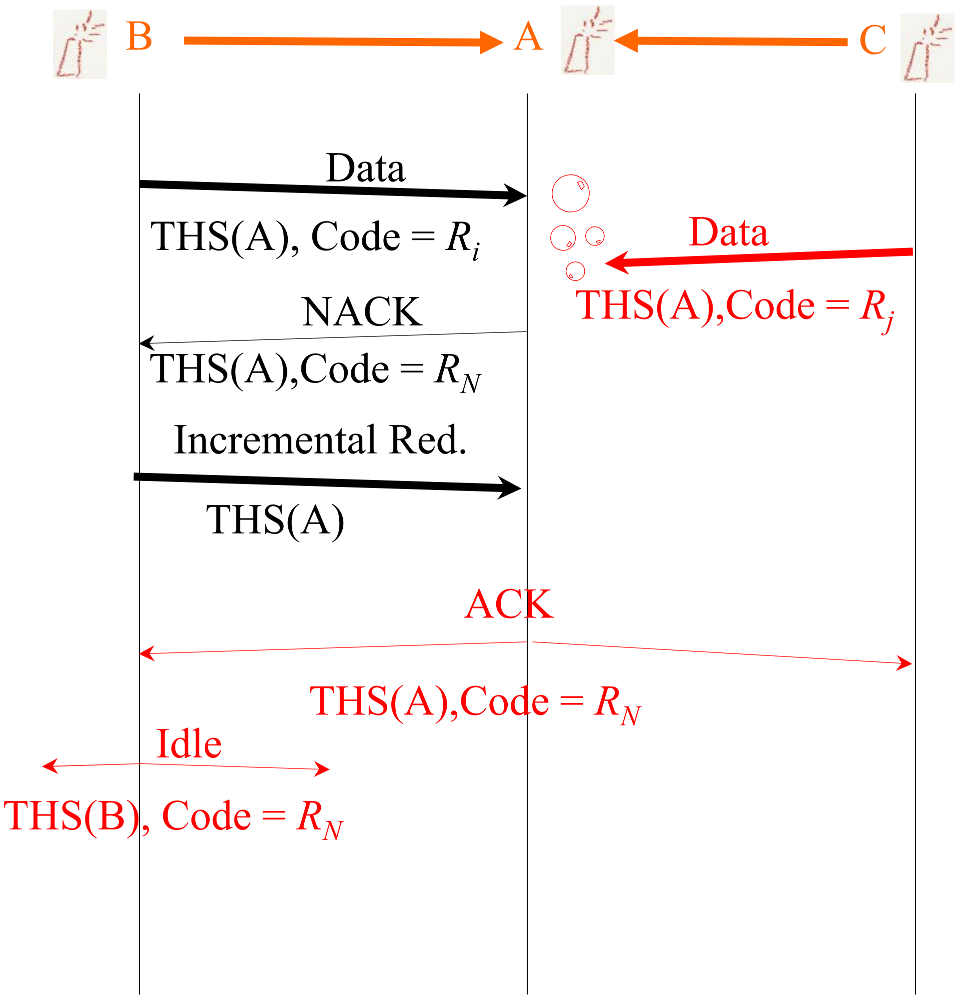
- This avoids most hard failures and adapts to varying channel (mobility, fading, interference)

- Acks / Nacks sent on lowest rate code in the reverse direction

Concurrent Access

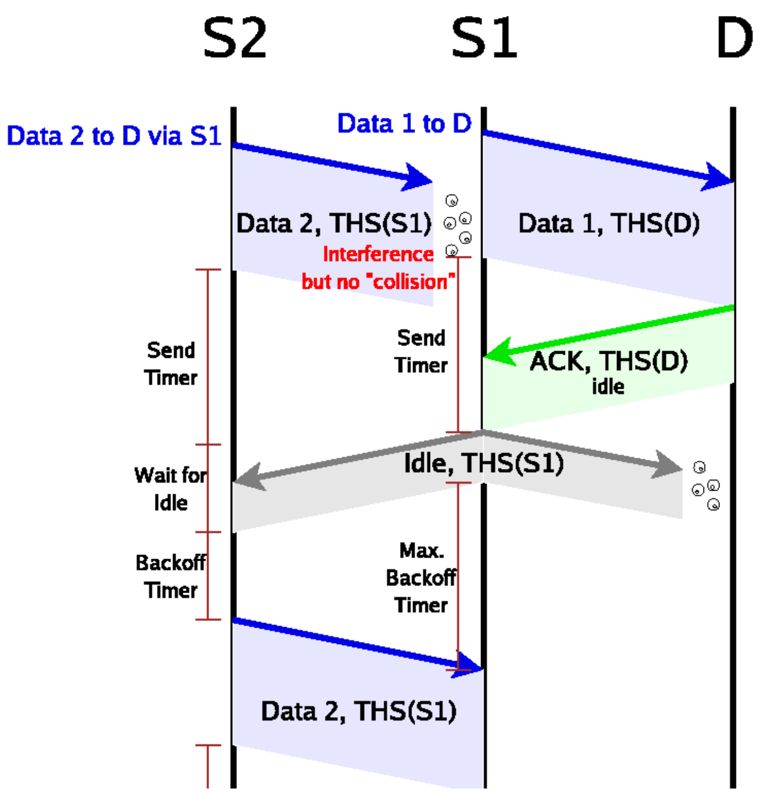
- Concurrent access to different destinations occurs without direct coordination
  - dynamic channel coding adapts automatically
- Access to same destination requires a mutual exclusion protocol
  - between competing sources
  - to arbitrate between sending and receiving
- Our "private MAC" protocol is a combination of invitation and receiver based

Concurrent Sources Do Not Collide

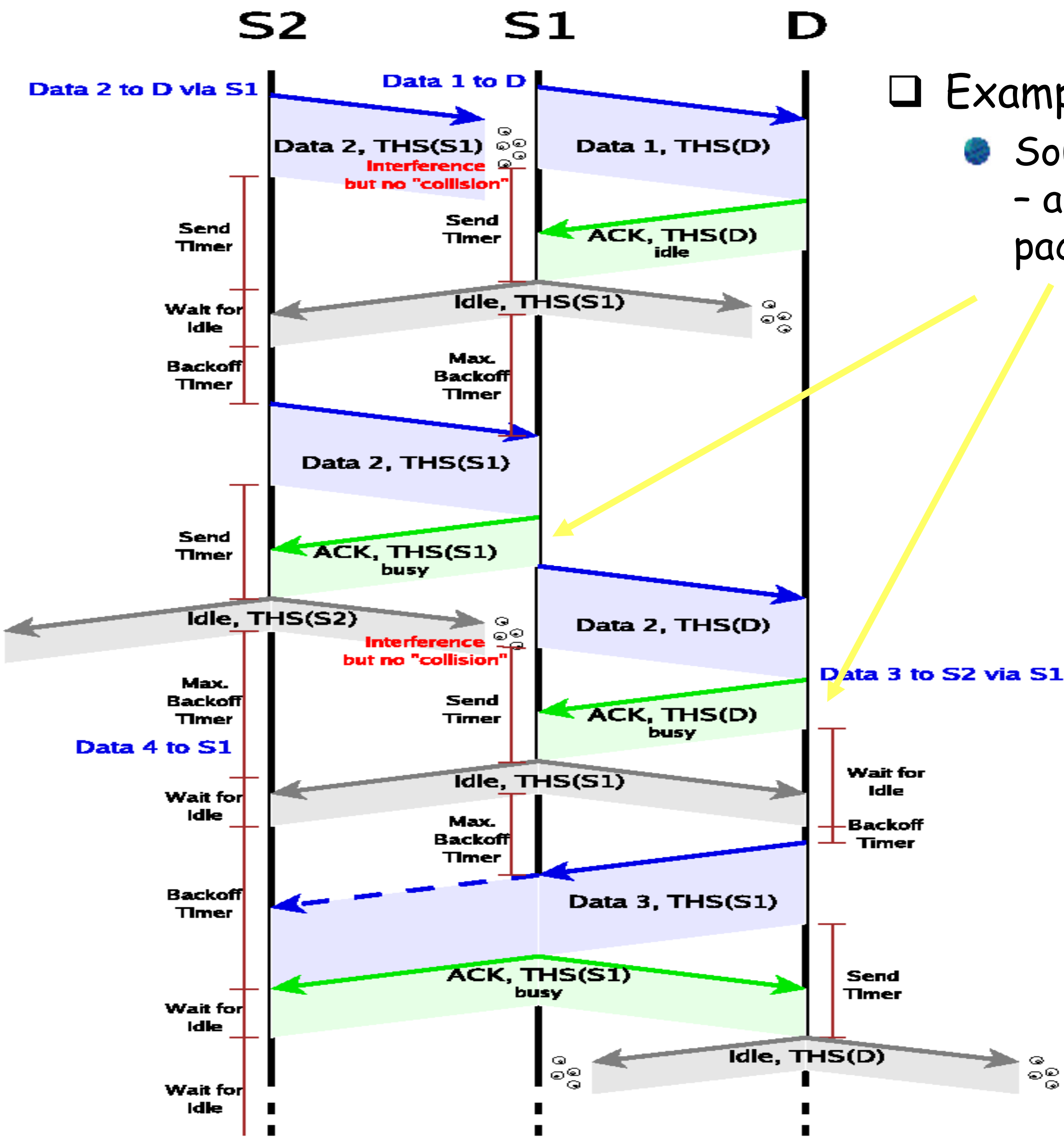


- *C* attempts to transmit to *A*
  - *A* is busy
- no collision, interference
- *C* waits for either
  - Ack
  - or Idle

In ad-hoc network, interplay between sending / receiving requires careful tuning



- *S2* has data to D *via* S1
  - send attempt by S2 fails
- Idle/Busy in acks and Idle signal are used to avoid failed attempts
  - node must send Idle after sending
  - node *may* send Idle or Busy (in ack) after receiving
- Examples
  - S1 sends Idle after sending Data 1 – frees S2
  - D sends idle in ack



- Examples
  - Sources sends busy in ack – allows sending a queued packet

Simulation Results: No Collapse for Many Users

- We implemented the Dynamic Channel Coding MAC in ns2, based on tables computed in Matlab
  - we redesigned ns2 PHY to support interference /collision during a transmission
- We compared the performance to
  - mutual exclusion (TDMA, Random Access); power control

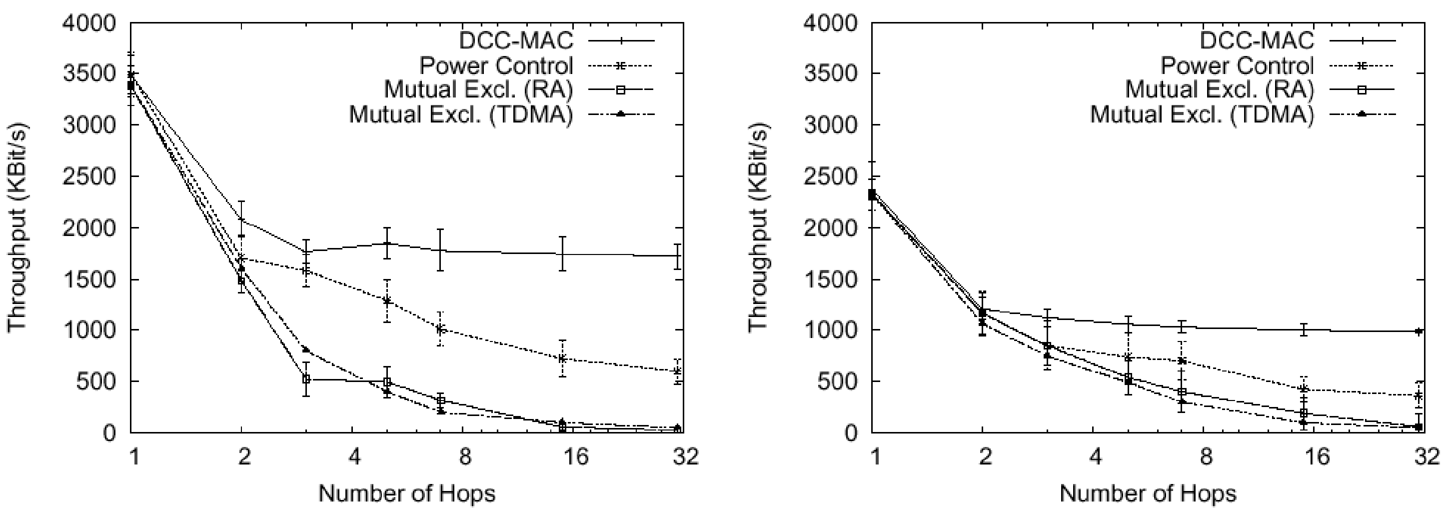


Fig. 7. Throughput on the multi-hop network for UDP (left graph) and TCP (right graph). We show throughput vs. number of hops. There is almost no drop in throughput for the DCC-MAC as the number of hops increases.

Conclusion

- We have designed a multiple access protocol for very low power UWB
- Design is joint with Physical Layer
- Uses other ingredient than classical MAC protocols
- Enables very low power UWB

More Information

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