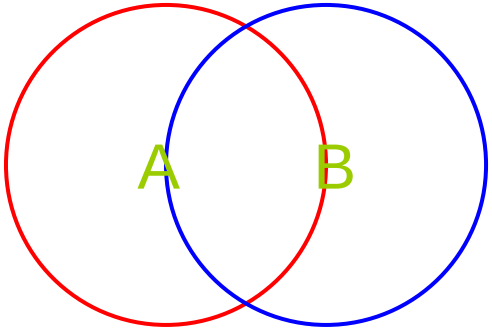
RID:
Radio Interference Detection in Wireless Sensor Networks

INFOCOM 2005

Outline

- Introduction
  - Connectivity-Interference / Interference-Connectivity
- Two Interference Detection Protocols
  - RID
  - RID-B
- Performance evaluation
- Conclusions and Discussions

Connectivity-Interference / Interference-Connectivity assumption



If node A can interference with node B's reception, then node B is within in the node A's communication range.

↕

If node B is within in the node A's communication range, then node A can interference with node B's reception.

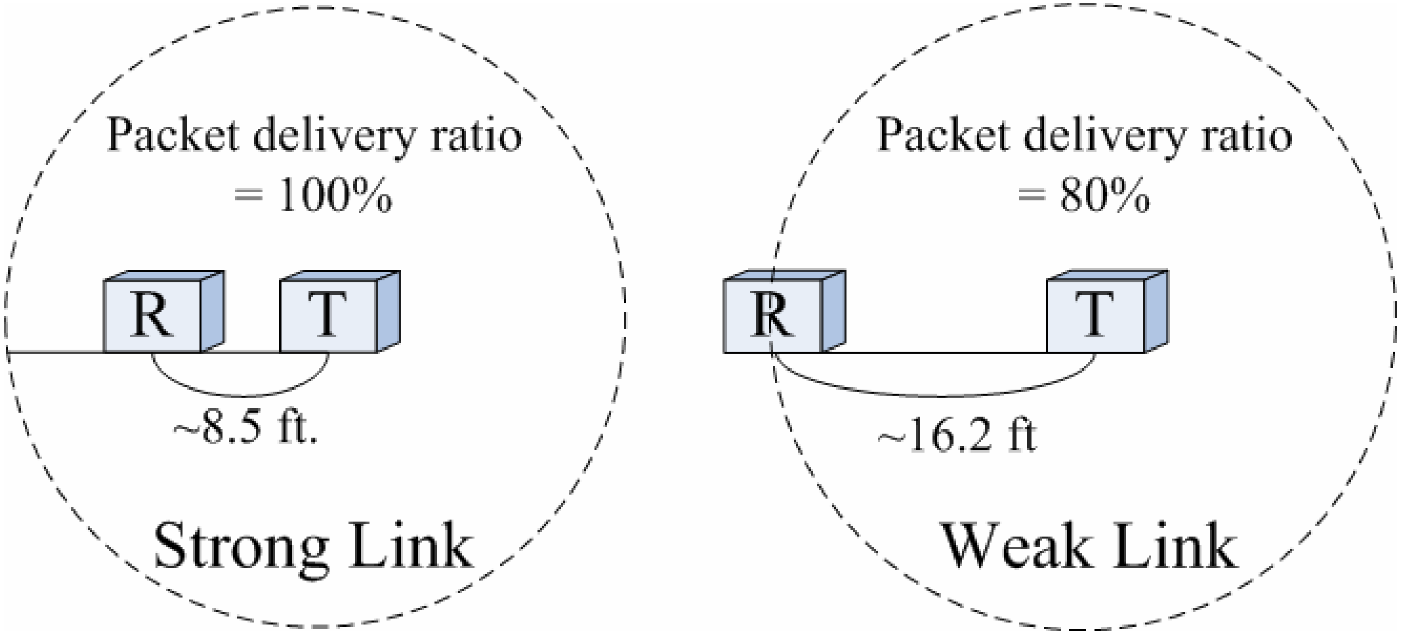
[Connectivity, Interference]

- Connectivity-Interference
  - Connectivity leads to interference
- Interference-Connectivity
  - Interference comes from connectivity

- **Are these assumptions always valid?**

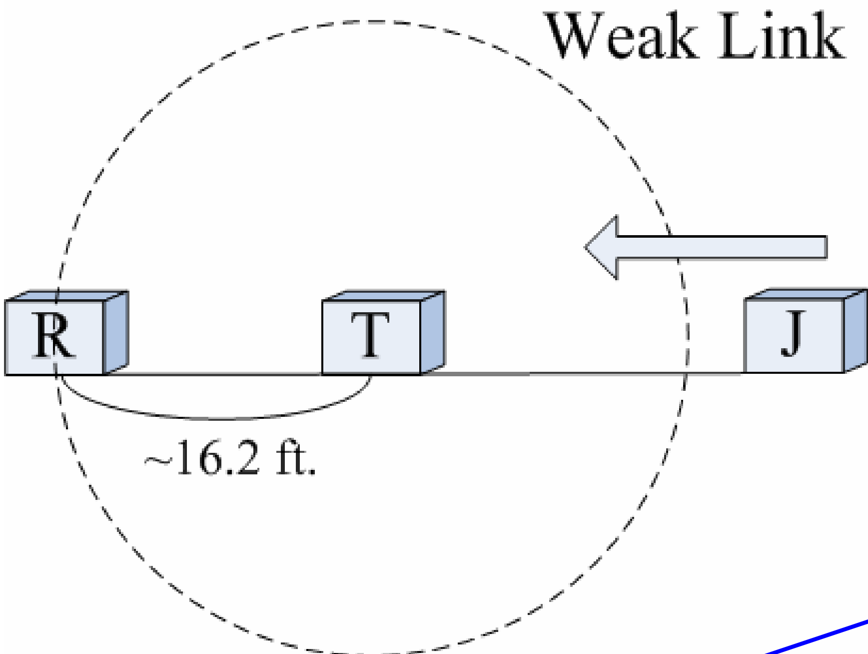
Answer: NO

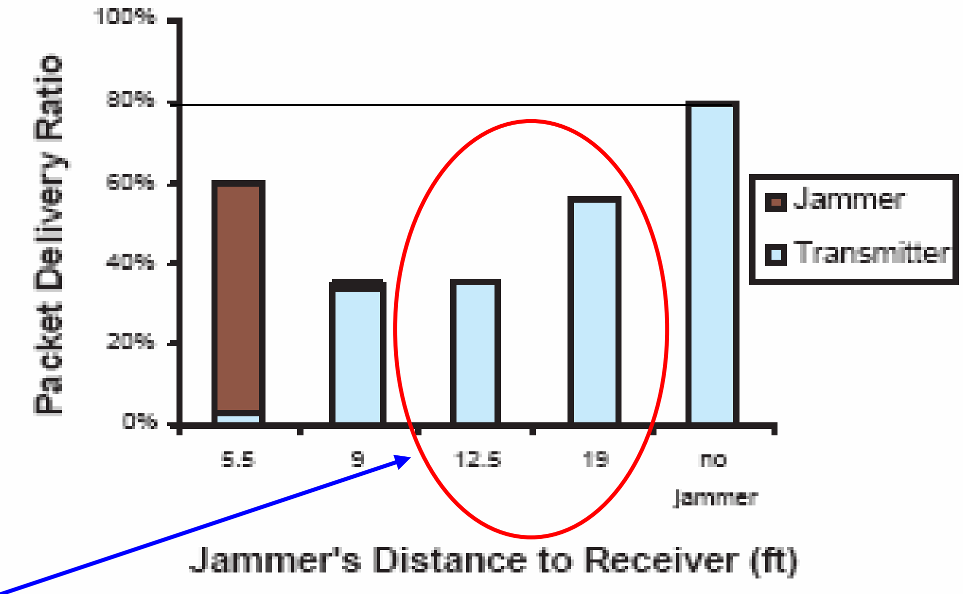
- These assumptions depend on the link quality.
  - Strong or Weak



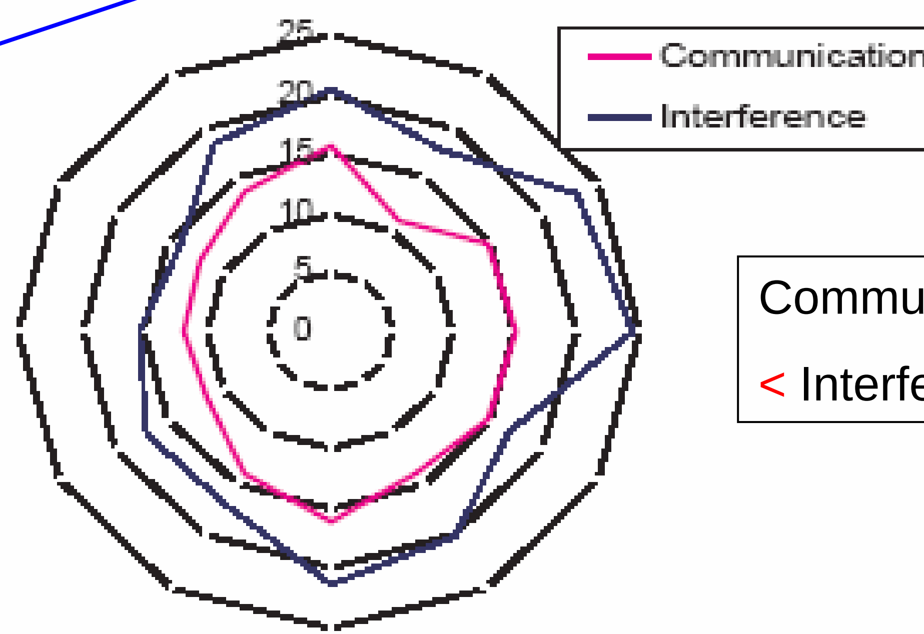
Experiment on Radio Interference

- MICA2 platform
- Disable carrier sensing and backoff operations in MAC layer
  - To ensure that all nodes can transmit simultaneously
- With no interference (only transmitter and receiver)
  - Strong link
    - ~ 8.5 ft.
    - Packet delivery ratio = 100%
  - Weak link
    - ~ 16.2 ft.
    - Packet delivery ratio = 80%



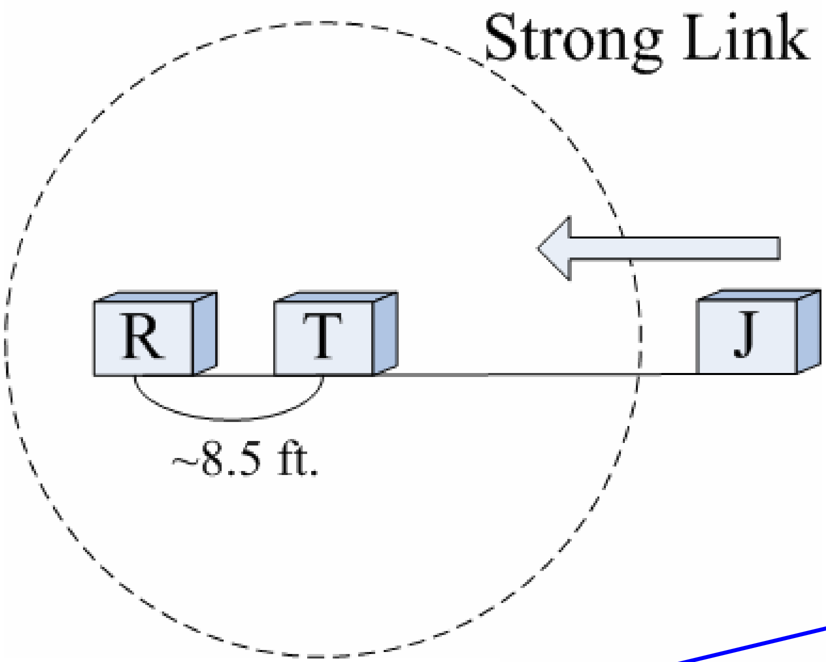


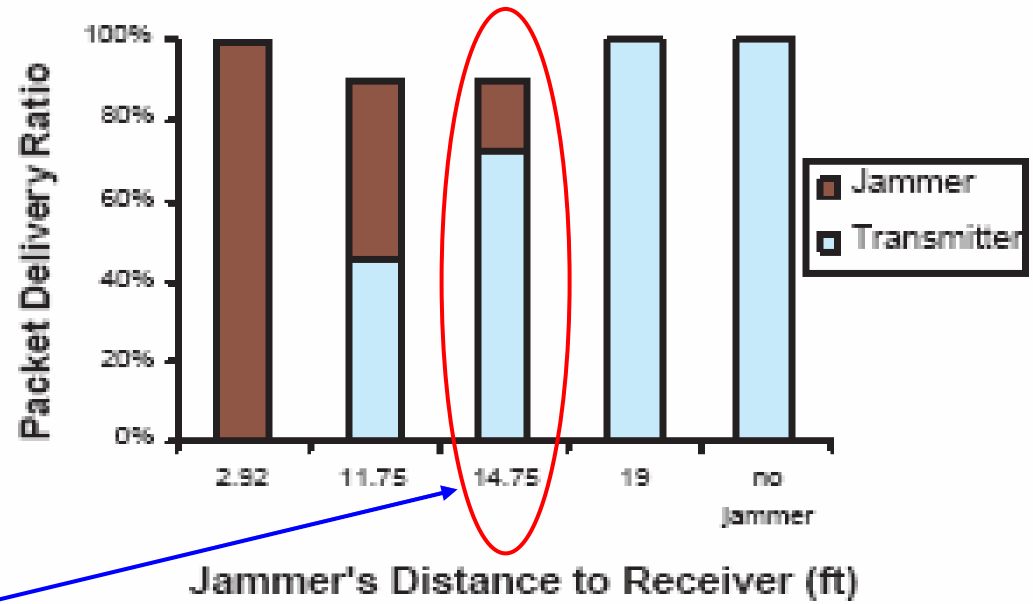
Distant Jammer still interferes with packet delivery ratio



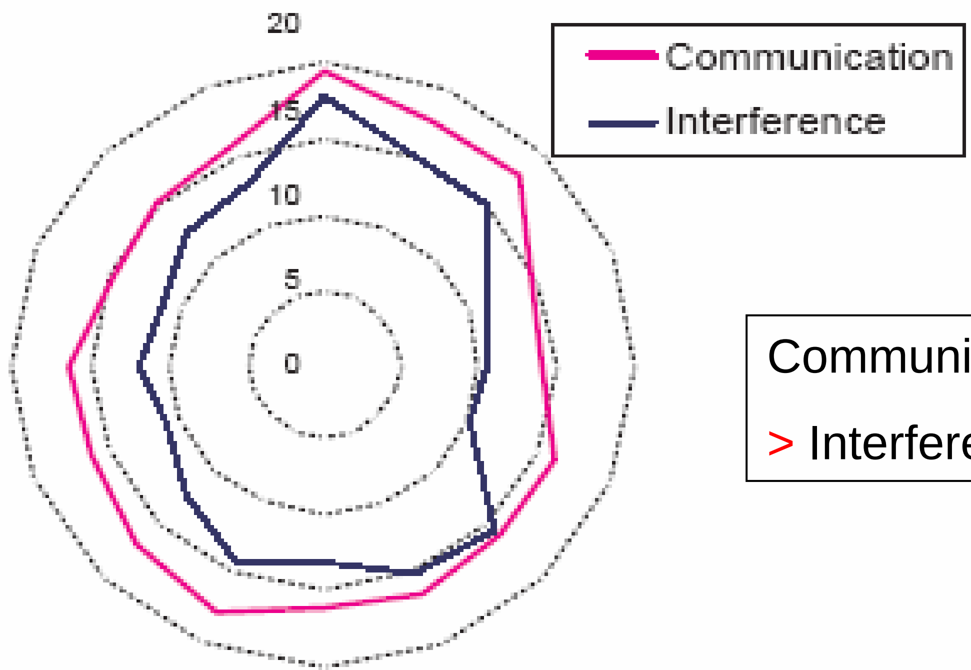
Communication range

< Interference range





Transmitter's strong signal dominates the interference signal



Communication range

> Interference range

Summary

- In weak link case:
  - Interference does not necessarily imply connectivity
  - Distant nodes still interfere with transmissions
- In strong case:
  - A connectivity does not necessarily result in interference
  - Transmitter's strong signal dominates the interference signal
- Communication range $\neq$ Interference range
  - It depends on how strong the link is

Goal:

To design collision-free MAC protocol, without knowing the interference relations among nodes.

Two Interference Detection Protocols

- RID: Radio Interference Detection Protocol
- RID-B: RID lightweight version

RID Protocol

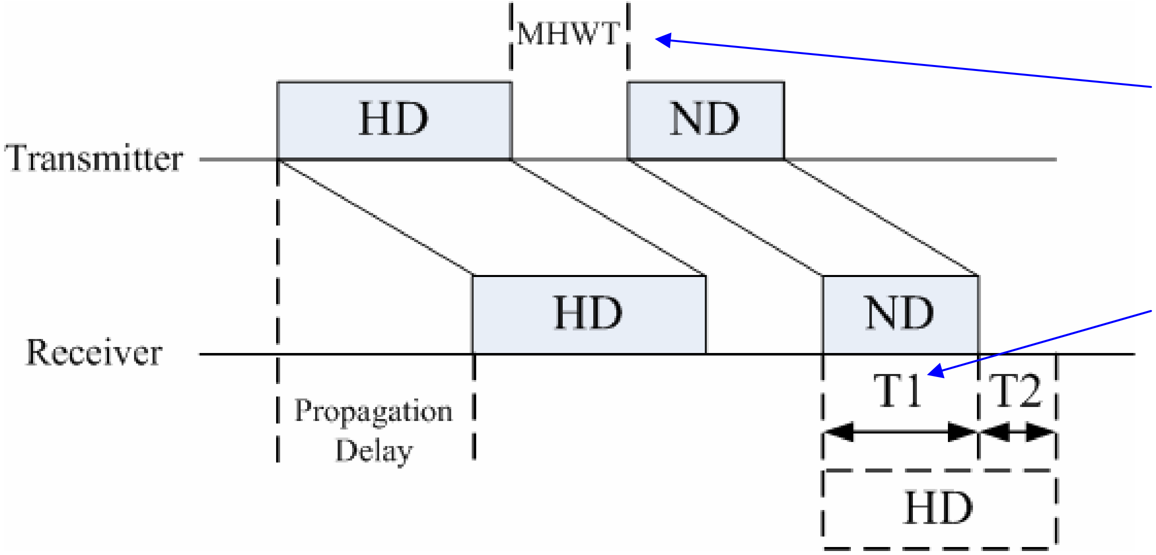
Three steps

1. HD-ND detection
2. Information sharing
3. Interference calculation

1. HD-ND Detection (1/7)

- Transmitter broadcasts a HD packet and immediately follows it with a ND packet.
- HD packet: High Power packet
  - Node ID (2 bytes)
  - Packet type (1 byte)
- ND packet: Normal Power packet
  - A fixed size training packet
  - It is used to estimate the interference strength

1. HD-ND Detection (2/7)



MHWT: Minimal Hardware Wait Time

Sense the signal strength during the T1 time period

- Detection estimation rule:

(threshold = background noise)

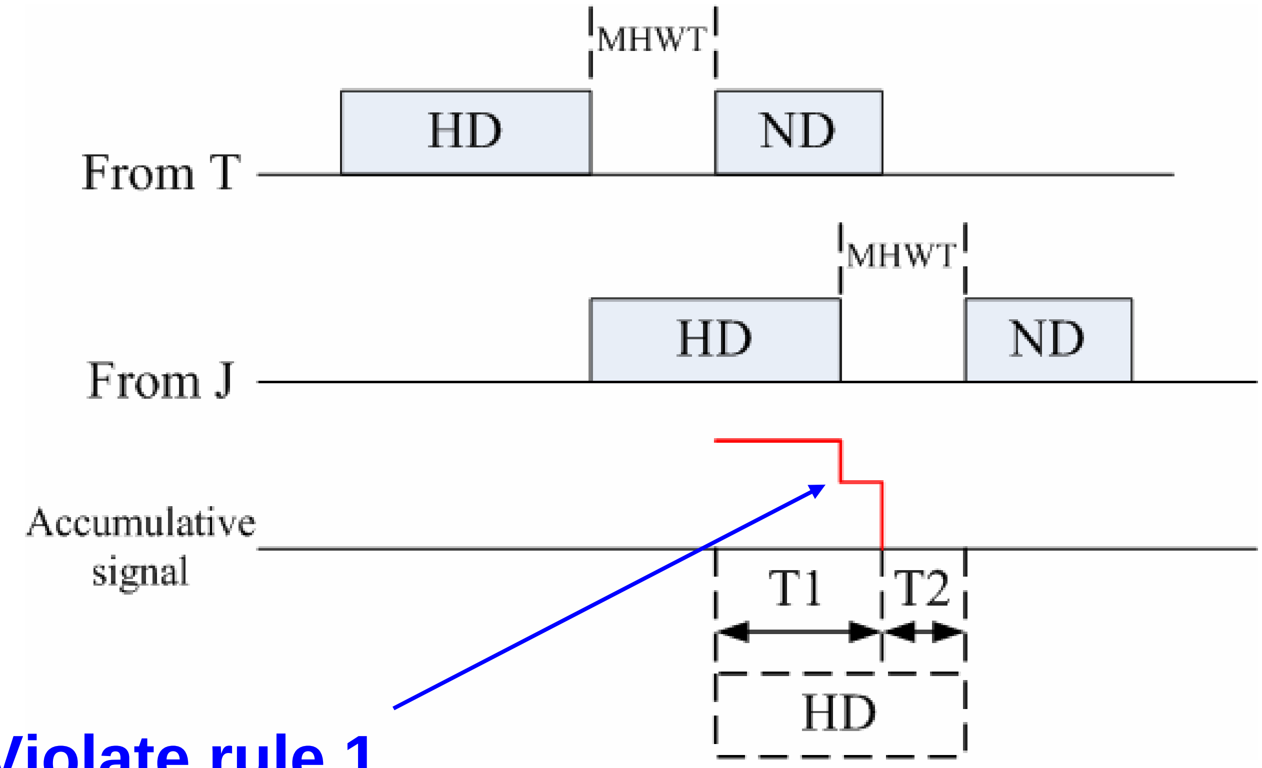
If < threshold: the transmitter's interference is extremely weak, does not record any information

If > threshold: records the (transmitter's ID, power level)

1. HD-ND Detection (3/7)

- The add-on rule
  - In order to solve that multiple HD-ND detection sequences from different transmitters may overlap.
  1. The power level sensed during time period *T*1, which is determined by the fixed length of ND packets, is stable.
  2. The power level sensed during time period *T*2, which is determined by the fixed size of both ND and HD packets, is always as low as that of the background noise.

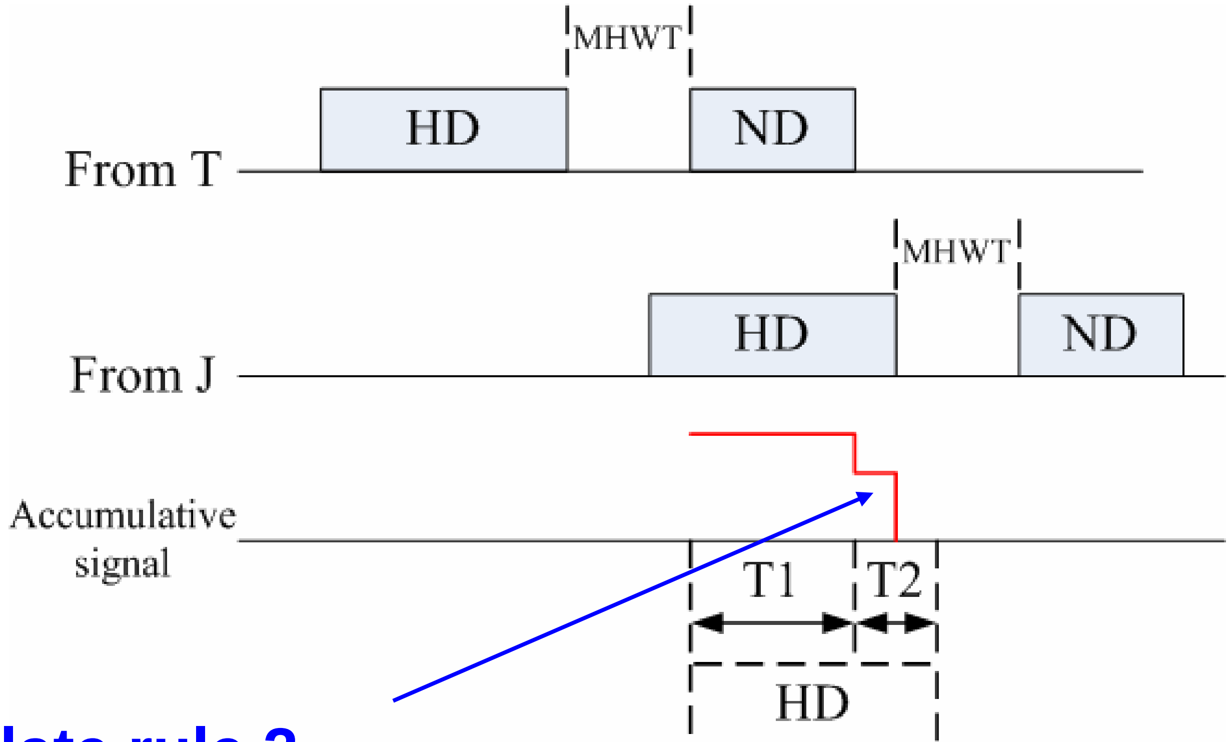
1. HD-ND Detection (4/7)



Violate rule 1

(not stable in T1)

1. HD-ND Detection (5/7)

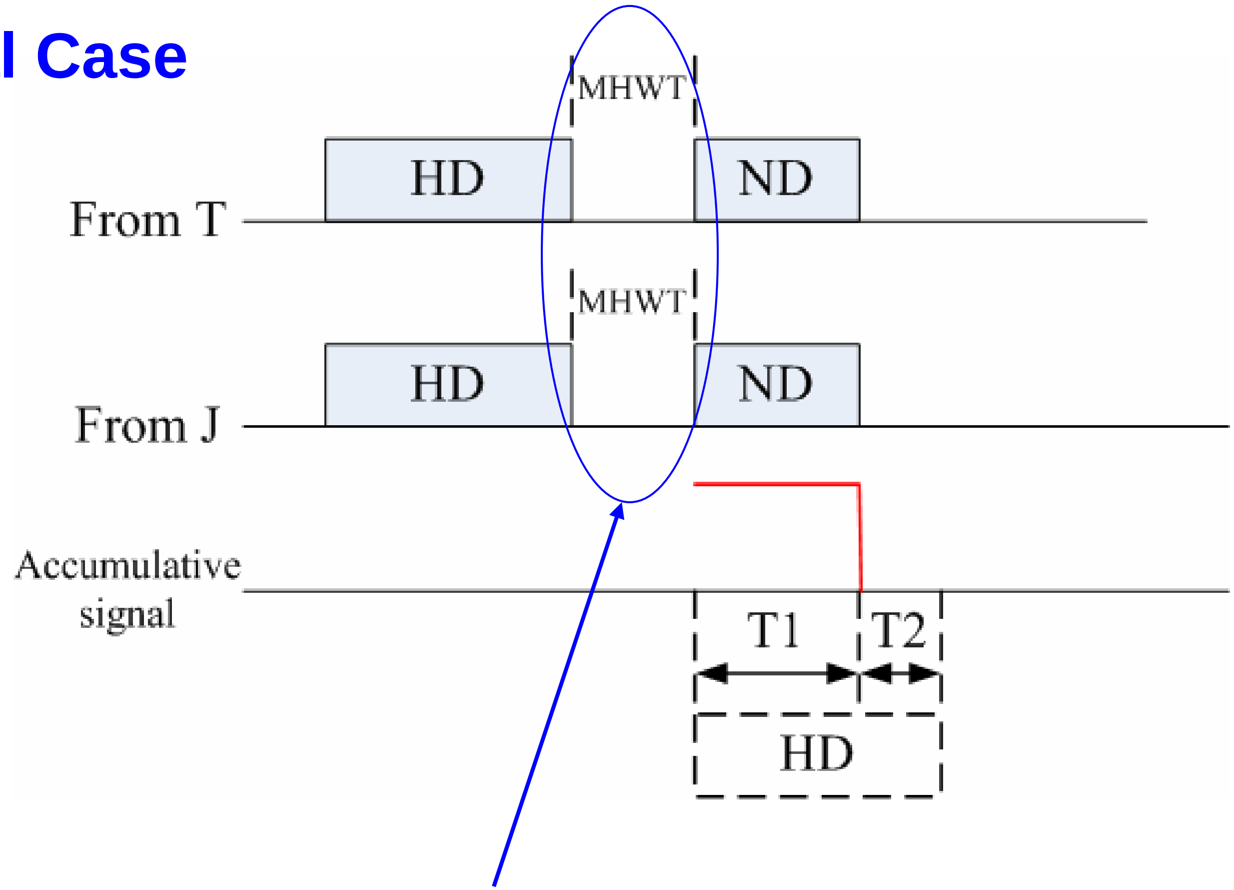


Violate rule 2

(not as low as noise)

1. HD-ND Detection (6/7)

Special Case



The probability such a case happen is low

1. HD-ND Detection (7/7)

- If the detection result violates the add-on rules, the result is not useful and marked invalid.
- All these (transmitter's ID, power level) pairs are put in a local table of the receiver, called *Interference_In* table

2. Information sharing

- The high power broadcast packet is used for each node to broadcast the interference information in its own *Interference_In* Table
- Interference_Out Table
  - This table contains information of nodes on which node R has potential interference
- Interference_HTP Table
  - This table contains information of nodes that are hidden from node R, when one of R's neighbor is the receiver

3. Interference calculation

SNR threshold for correct packet reception

General case

Background noise around node D

$$N_k(D) = \{(i_1, i_2, \ldots, i_k) \mid$$

K simultaneous transmitter

$$(P_{i_1 D} < (P_{i_2 D} + \ldots + P_{i_k D} + P_{idle}) * SNR_T$$

$$\wedge (P_{i_1 D} > receiver\_sensivity)$$

Power level form node i_1

$$\wedge (\forall t (2 \le t \le k-1 \Rightarrow$$

$$(\forall j_1, \ldots, j_{t-1} (i_2 \le j_1, \ldots, j_{t-1} \le i_k) \Rightarrow$$

$$(i_1, j_1, \ldots, j_{t-1}) \notin N_t(D))))\}$$

Make sure that this calculation is for K

3. Interference calculation

Simple case: K=2

$$N_2(D) = \{(i_1, i_2) \mid (P_{i_1 D} < (P_{i_2 D} + P_{idle}) * SNR_T \wedge (P_{i_1 D} > receiver\_sensivity)\}$$

- Two results:
  - No interference, i_1's signal can be received by node D
  - Node i_1's signal can be disturbed by node i_2's signal

RID-Basic (RID-B) Protocol --lightweight RID (1/4)

- Motivations:
  - RID needs many information about the overall networks.
  - RID-B is designed for sensor networks
    - It is difficult to get overall information about the networks
    - Most applications are event-based applications
    - Limited power supply
    - Limited communication bandwidth

RID-B Protocol (2/4)

Two steps:

1. HD-ND detection
   - Detection rule and add-on rule for receiver are the same with RID.
   - Nodes are still running HD-ND detection estimation operations.
   - Build *Interference_In* Table

2. Information sharing
   - The *Interference_Out* and *Interference_HTP* tables are also build in the same way.

RID-B Protocol (3/4)

Original: (ID, power level)

Three differences:

1. The *Interference_In* table gets reorganized again, according the following condition:

$$P_{\min R} < (P_{JR} + P_{idle}) * SNR_T$$

$$where \quad P_{\min R} = \min\{P_{iR} \mid i \neq J$$

$$\wedge P_{iR} > receiver\_sensitivity\}$$

The most distant neighbor node R can hear packet from

Then, remove power-level

After reorganizing, the table only consists of rows of transmitter's IDs.

RID-B Protocol (4/4)

2. Multiple transmitters are not been taken into consideration
   - Because of the probability that these packets overlap is very low.
   - The payload of MAC layer is short, usually 32 bytes
3. There is no interference calculation phase in RID-B

- Compare with RID, RID-B is simple and lightweight

Performance evaluation

- Compare with a distributed TDMA protocol, NAMA (Node Activation Multiple Access) [2].
  - In NAMA, modes within two comm. hops are scheduled to avoid transmitting at the same time, to avoid collision.
  - NAMA protocol only uses the knowledge of comm. range. (no interference range)

Performance evaluation

- Three experiment groups
  - Different system load
  - The sensitivity to different ICR ratio
  - The sensitivity to different SNR threshold
- In each group, the performance is evaluated with 5 metrics:
  - Average single hop loss ratio
  - Average single hop transmission time
  - #retransmission
  - #control packet
  - Energy consumption

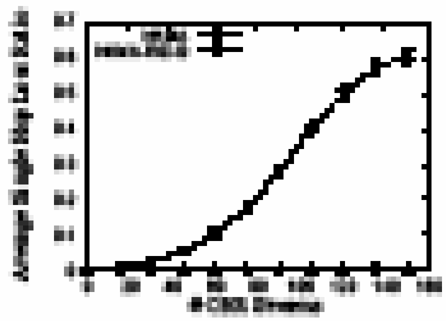
Performance evaluation

Simulation parameters

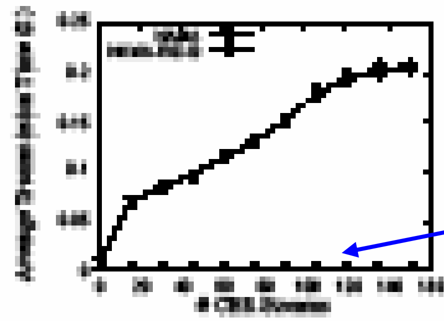
- Area: 144m * 144m
- #node:144 (uniform placement)
- Application: Many-to-one CBR streams
- Payload size: 32 bytes
- BW: 250kb/sec
- Radio range: 25m

1.

Apply different system load



(a) Loss Ratio

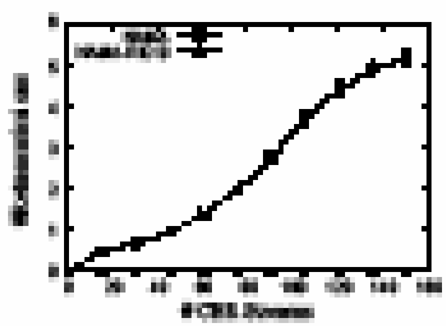


(b) Trans. time

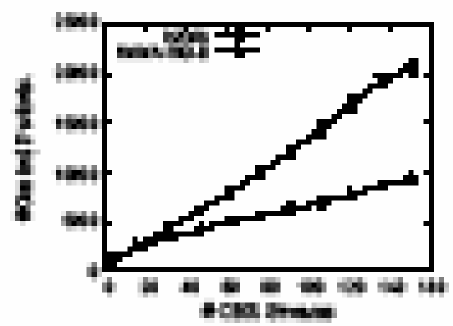
4 msec

No retransmission

No loss



(c) #Retransmission



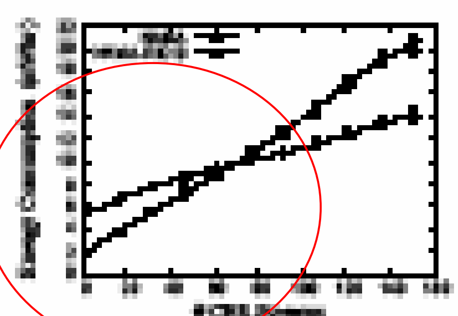
(d) #Control Packet

Two resaons:

- More ACKs
- More loss, more retrans.

From (a) and (c), impossible!

HD packet consumes more power than ND packet

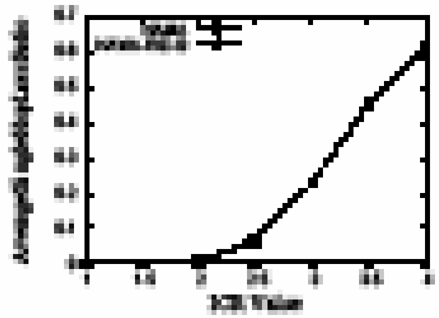


(e) Energy consumption

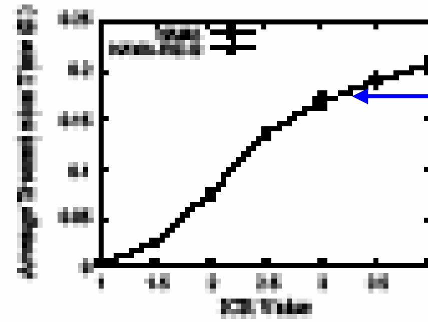
2.

Apply different ICR ratio

$ICR=R_I/R_C$

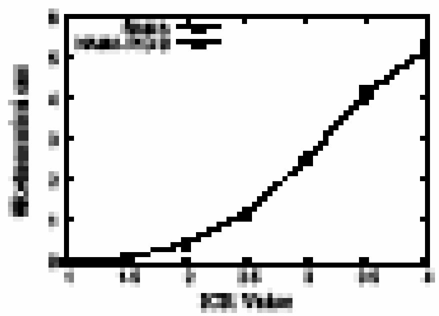


(a) Loss Ratio

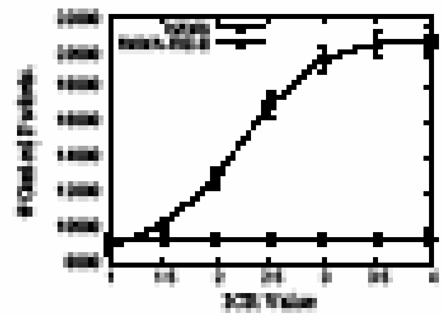


(b) Trans. time

- Increase from 4 ms to 215 ms
- Interference is serious!



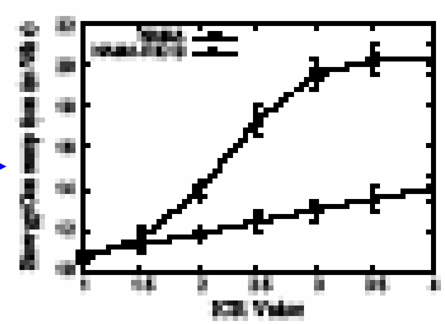
(c) #Retransmission



(d) #Control Packet

No retransmission

No loss



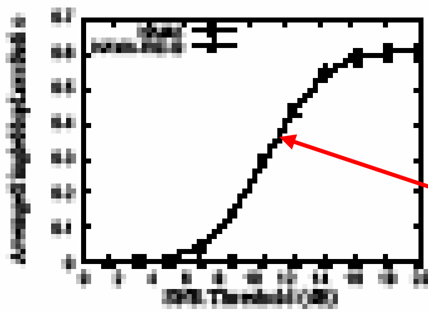
(e) Energy consumption

HD packet consumes more power than ND packet

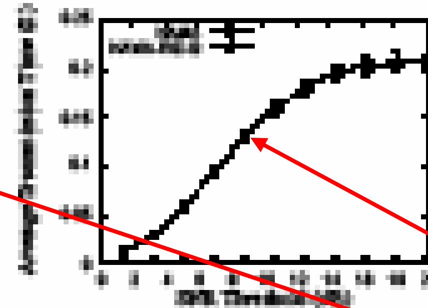
3.

Apply different SNR ratio

$SNR = P_S / P_N$



(a) Loss Ratio

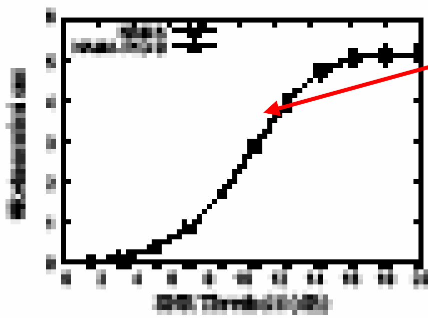


(b) Trans. time

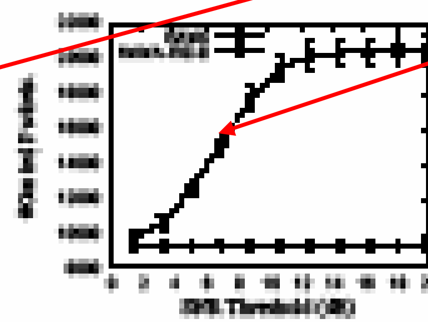
When SNR increasing, a transmission gets easier to be interfered with by nodes form longer distances

No retransmission

No loss

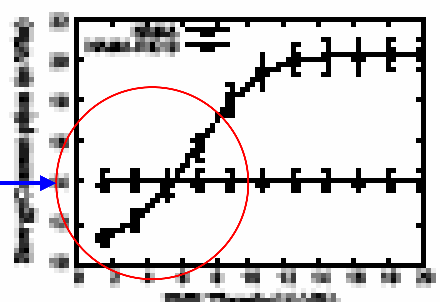


(c) #Retransmission



(d) #Control Packet

HD packet consumes more power than ND packet



(e) Energy consumption

Conclusions

- First time to detect radio interference among nodes in run-time system
- The authors show that

Communication range $\neq$ Interference range

- The connectivity/interference assumptions are not always valid.

References

[1] G. Zhou, T. He, J. A. Stankovic and T. Abdelzaher, “RID: Radio Interference Detection in Wireless Sensor Networks,” in IEEE INFOCOM 2005.

[2] V. Rajendran, K. Obraczka, and J.J. Garcia-Luna-Aceves, “Energyefficient, collision-free medium access control for wireless sensor networks,” in *ACM SenSys 2003*, November 2003.

[3] L. Bao and J. J. Garcia-Luna-aceves, “A new approach to channel access scheduling for ad hoc networks,” in *ACM MobiCom 2001*, July 2001, pp. 210–221.