# Experimental study of the effects of Transmission Power Control and Blacklisting in Wireless Sensor Networks

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**CS525M**

# Introduction

- Low-power wireless channels
  - Susceptible to fading
  - Susceptible to interference
- Prior research
  - Idealized assumptions
    - …leading to idealized simulations

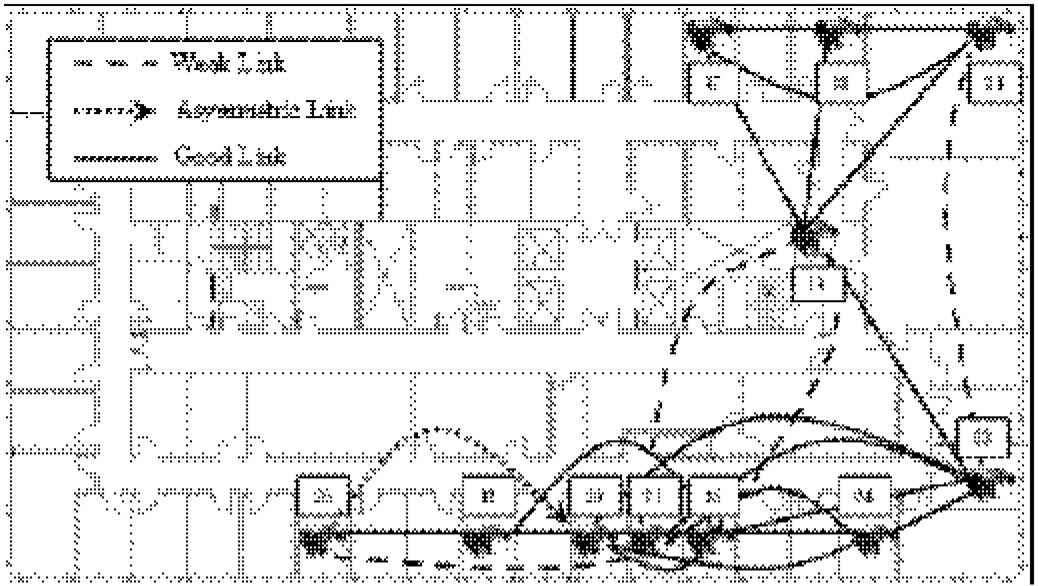
# Introduction

- Consistent link quality
  - Transmission power control (TPC)
  - Link (and packet) blacklisting
- Prior research
  - Power and capacity instead of reliability
  - Theoretical, not experimental

# Background

- Directed Diffusion Routing
  - Two-phase pull
    - Data sink sends interest
    - Sources reply with exploratory data
    - Sink returns positive/negative reinforcement
    - Positive path develops, returns data
  - One-phase pull
    - Sink sends interest
    - Source sends data

# Directed Diffusion in Practice




Weak = <90% PRR

Good = >=90% PRR

Asymmetric links are good in one direction.

- **One-phase pull: 43-58% Packet Reception Rate (PRR)**
- **Two-phase pull: 72-83% PRR**
- **Conclusion: unreliable links are worse than no links!**
  - **If a reliable route exists**
  - **…or can be created with TPC and blacklisting**

# Applying Transmission Power Control

| Pwr / Link | 0 | 1 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|---|
| 11->31 | 54.3 | 86.3 | **92.4** | 100 | 100 | 100 | 100 |
| 31->11 | 0 | 27.2 | 83 | 85.7 | **96.8** | 100 | 100 |

Table. 1. Packet Reception Rate for the links between node 11 and node 31 at increased Transmission Power levels (dBm).

- **Empowering a weak link…**
  - **…in sparse network, makes TX possible**
  - **…in a dense network**
    - **Tends to be cheap (dBm cost per PRR)**
    - **Tends to produce new weak links**
      - **Blacklisting solves this**
    - **Tends to reduce network capacity**

# One Receiver, Three Transmitters

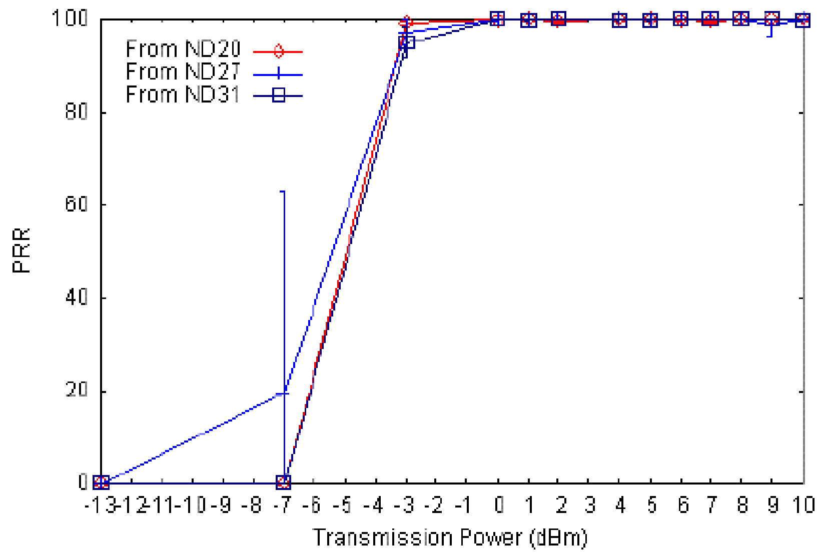



Fig. 2. Packet Reception Rate from different Transmitters to the same Receiver at 14 m distance.

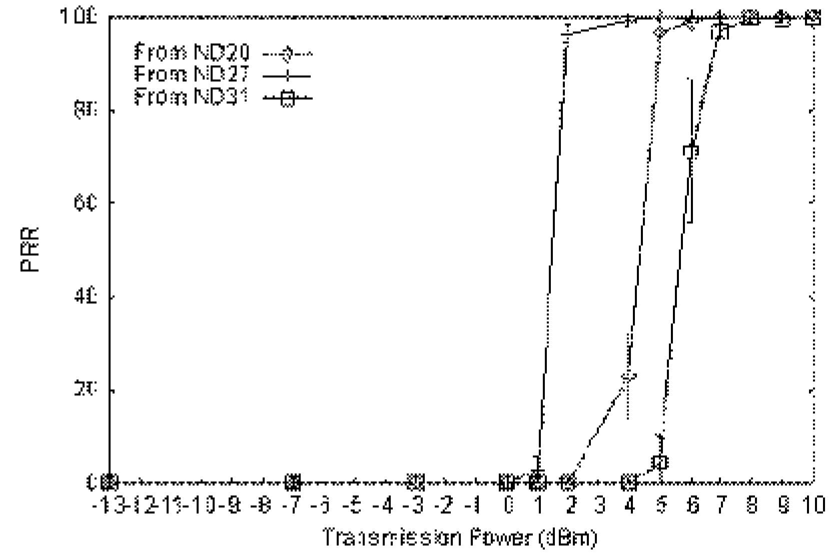



Fig. 3. Packet Reception Rate from different Transmitters to the same Receiver at 23 m distance.

# One Transmitter, Three Receivers

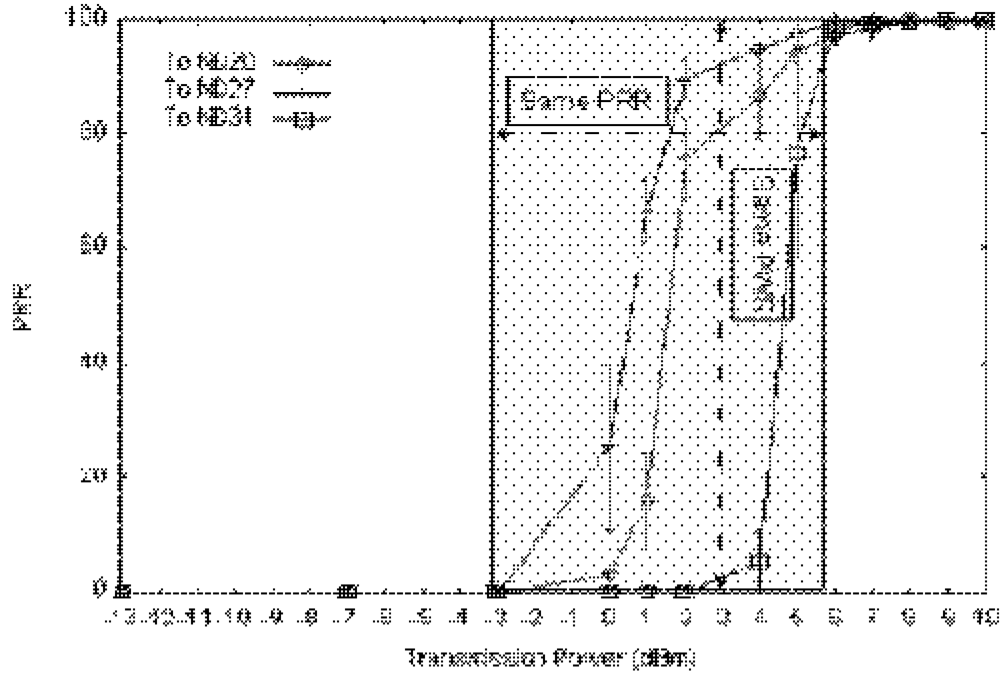



Fig. 4. Packet Reception Rate from the same Transmitter to different Receivers at 23 m distance.

# Experimental Summary

- Hardware Variation
  - Trivial at high power / close range
  - Significant at low power
  - Compensate with power control
  - Likely to get worse…
    - Cheap sensor fabrication

# Wireless Link Distance

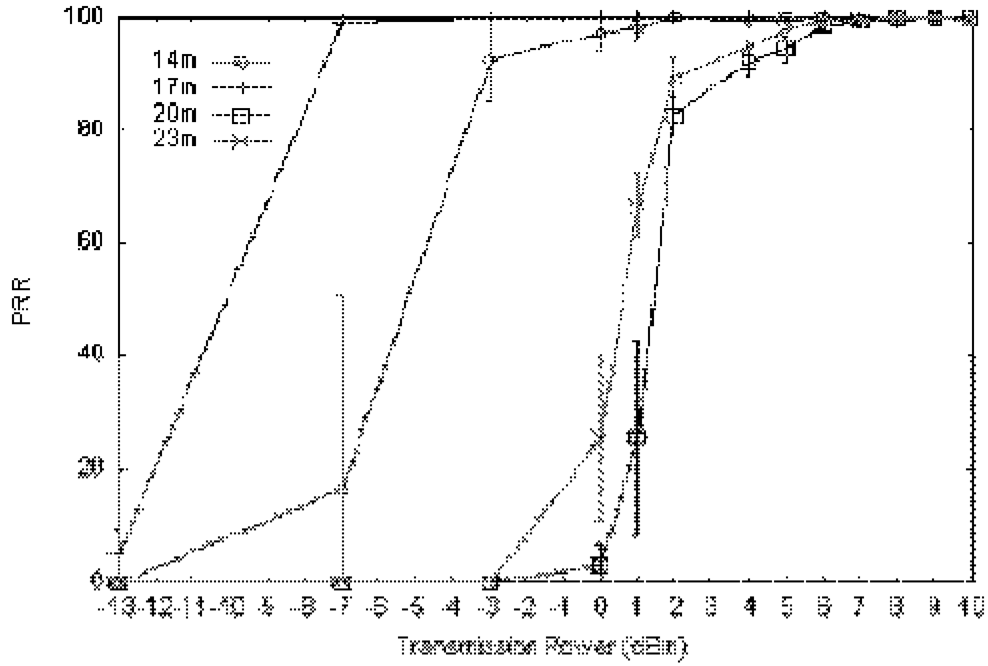



Fig. 5. Packet Reception Rate at different distance between node 34 (transmitter) and node 27 (receiver).

- **Indoor multi-pathing is a concern**
- **New good links can be created**

# Node Positioning

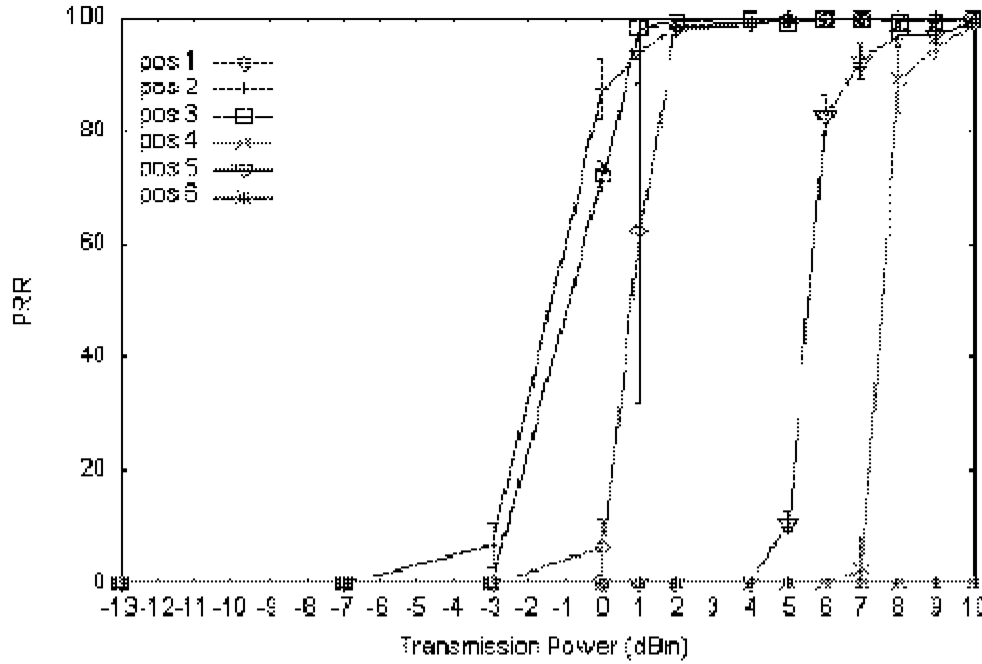
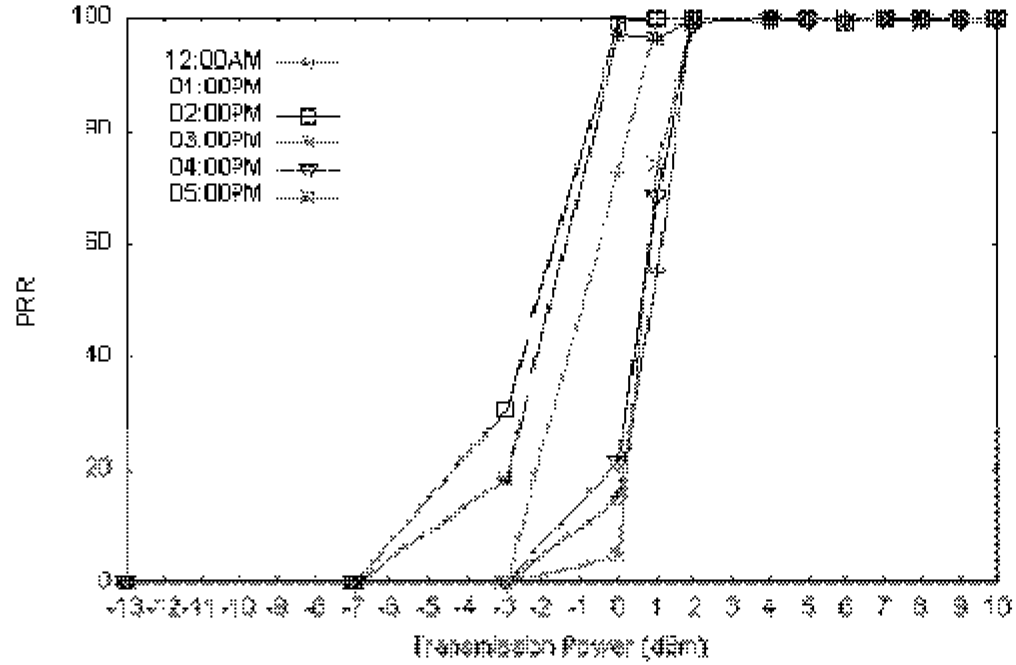



Fig. 6. Packet Reception Rates at five different receiver positions (pos 1-6) inside the same room at distance around 16m between node 12 (transmitter) and node 34 (receiver)

- **Again, indoor multi-pathing means small movements can destroy links**
- **Links can be regenerated with power control**

# Environment Over Time




a) Daytime link quality change (in PRR) for the LINK

- **Surrounding environment only affects the unreliable power range (-7 to 2 dBm)**
- **Night graph (not shown) had almost no change**

# Defining Reactive Links

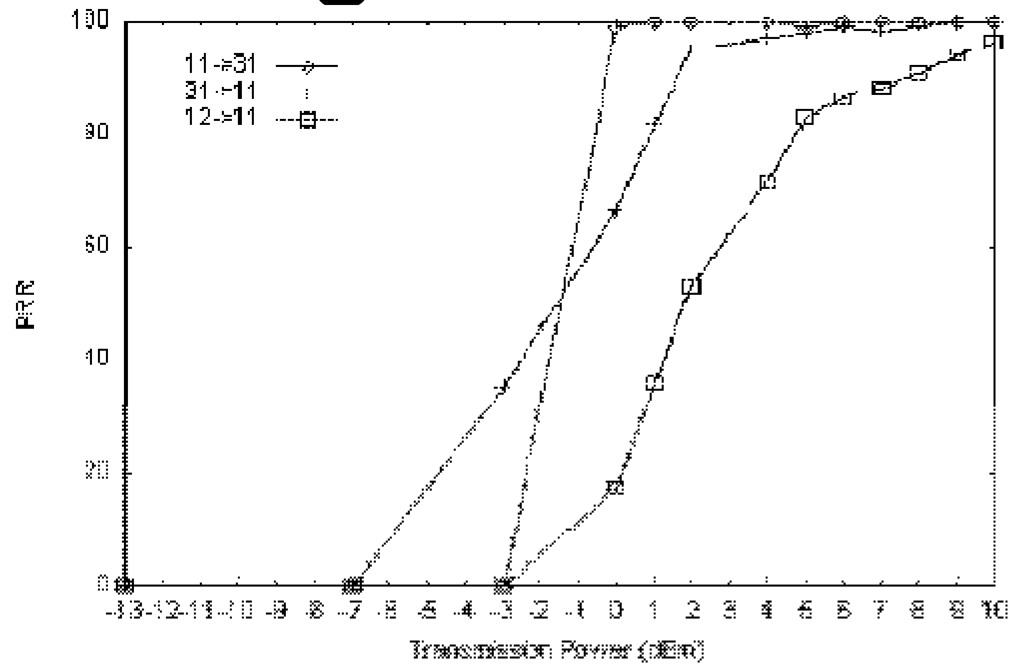



Fig. 8. Packet Reception Rate for three different links.

- **High PRR per dBm defines a reactive link**
- **Reactive links are hit harder by environmental changes**
  - **…but environmental changes only affect transmissions in the unreliable range.**

# Summary So Far:

# Power Conquers All?

# Proposed Approach: PCBL (Power Control and BlackListing)

- TPC used to control link quality
  - Establish good links
- Packet-based TPC
  - TX Power varies per packet
    - Depending on destination
    - Optionally, depending on QoS requirements
- Metric-based link quality estimation
  - PRR, not distance, used to quantify
- Blacklisting at adjusted power levels
  - Remove weak links created by increased power

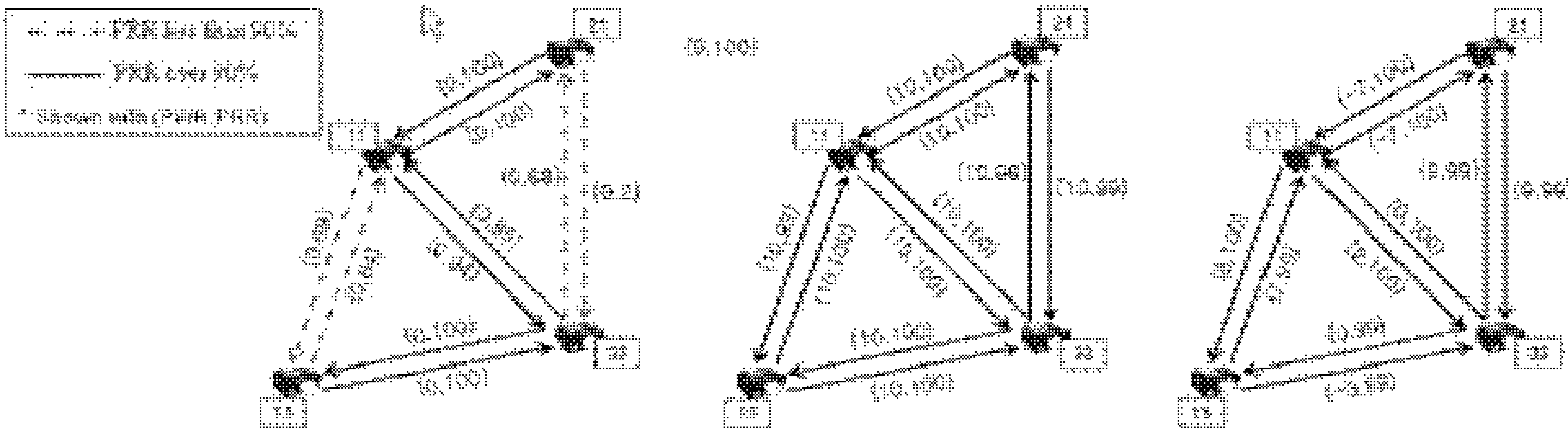
# PCBL (Optimize Before Routing)

1. Collect link statistics
   - A set of dBm:PRR measures for each link
2. Select a unicast TX power for each link
   - Lowest power that satisfies PRR minimum
3. Blacklist unreliable links
   - Or blacklist unreliable packet routes
4. Select a broadcast TX power
   - Highest TX power from step 2
5. Repeat at intervals to adjust to changes

# M-BL (On-demand optimization) Maximum-BlackList

1. Collect link statistics at max. power
2. Blacklist unreliable links
3. Apply routing protocol to find path
4. Identify unicast transmission power (as in PCBL) along that path

# Topology



(a) without transmission power control (b) with M-BL scheme (c) with PCBL scheme

Fig. 9. Topology change with different schemes. Each link shows (transmission power , PRR) pair information.

**(Their mouse pointer, not mine)**

# Evaluating Metrics

| PRR | 60-70 | 70-80 | 80-90 | 90-100 | 90-95 | 95-98 | 98-99 | 99-100 |
|---|---|---|---|---|---|---|---|---|
| STDEV | 40.5 | 23 | 18.8 | 3.4 | 19.8 | 10.8 | 2.2 | 0.89 |

Table. 2. Standard deviations for the links with different levels of PRR .

- **M-BL versus PCBL**
  - **More stable PRR versus power and capacity conservation**
    - **The greatest gains in power conservation provide the highest standard deviations**
  - **Careful selection of blacklist thresholds is necessary**

# Results

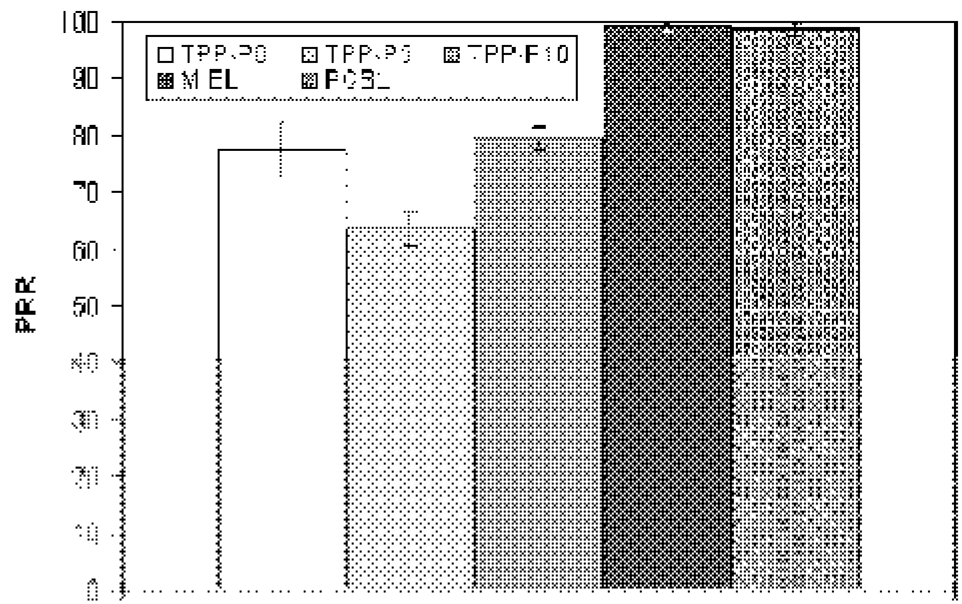



Fig. 10. Packet Delivery Rate from the experiments with five different schemes.

| Scheme | TPP-P0 | TPP-P5 | TPP-P10 | M-BL | PCBL |
|---|---|---|---|---|---|
| PDR | 77.5% | 63.6% | 79.5% | 99.2% | 98.7% |

Table. 3. Packet Reception Rate for each scheme

# Results Continued

| Scheme | TPP-P0 | TPP-P5 | TPP-P10 | M-BL | PCBL |
|---|---|---|---|---|---|
| PDR | 77.5% | 63.6% | 79.5% | 99.2% | 98.7% |

Table. 3. Packet Reception Rate for each scheme

| Difference | Unicast | Broadcast | Total | Per Packet |
|---|---|---|---|---|
| M-BL | + 75.4% | + 53.2% | + 67% | + 66.2% |
| TPP-P0 | + 3.5% | - 40.3% | - 13 % | + 10.8% |

Table. 4. The difference in energy consumption for packet transmission from our PCBL scheme

- **M-BL provides a steep power increase for 0.5% gain**
- **PCBL consumes more power per packet than TPP-P0**
  - **…but fewer retransmissions even it out**
- **Naively increasing power is counterproductive**

# Multi-Stream Results

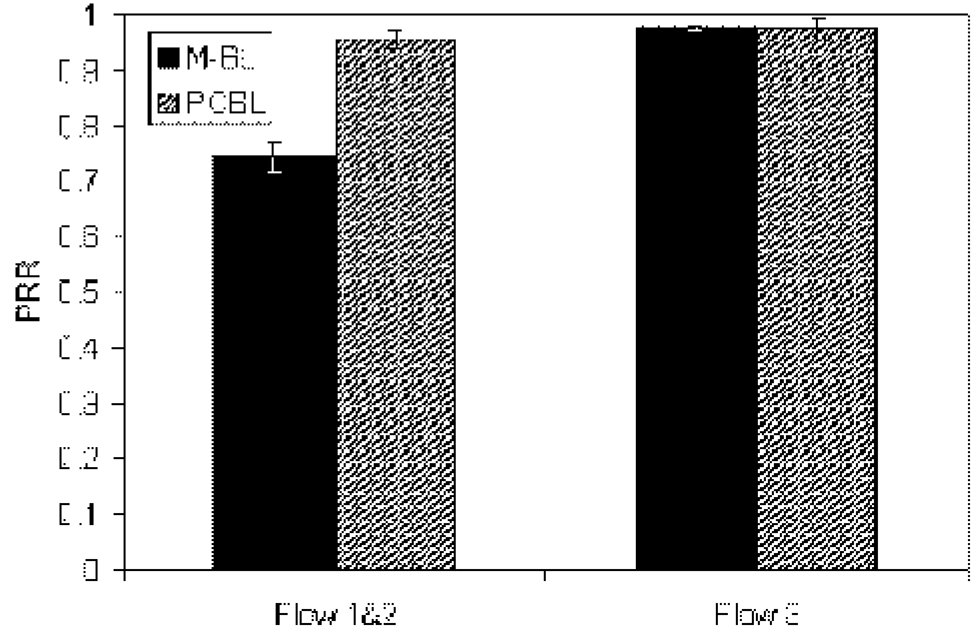



Fig. 11. Packet Delivery Rate from the experiments with three data flows

- **M-BL loses ground**
  - **Increased transmission power consumes more network capacity**
  - **Dense sensor networks exacerbate this**

# Proposed Optimizations

- Calculate link power on the fly
  - Adjust based on retransmission count
  - Adjust based on received signal strength change during data delivery
- Use asymmetric links
  - Useful for propagating broadcasts that require no response
  - Requires packet-based, not link-based, blacklisting

# Conclusions

- Pre-set power levels cannot cope
  - Naïve power increases are counterproductive
- M-BL may be optimal for some topologies and requirements
- PCBL appears to be a more flexible solution
  - …which, given the nature of sensor networks, may be critical
  - PCBL's concept of packet-based QoS may also gain relevance
- Latency?

# Questions?