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

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Introduction: Experimental Study, Power Control, and Blacklisting

Why experimental study ?

- **To identify the problems of idealized link quality approximation**
- **To capture complexities in real world low-power wireless links**

Effects of prevalent unreliable links

- Having unreliable link (weak/asymmetric link) is worse than having no links at all when bi-directional communication is required and there is a good multi-hop communication route to use between the sender and receiver.
- Significant drop in Packet Delivery Rate due to unreliable links

PC104 Testbed at USC/ISI

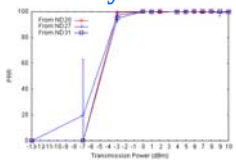
Effects of Tx power control

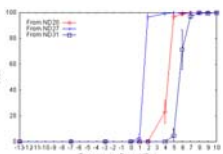
- **Attainable Benefits**
  - Link quality control of specific links
  - Discovery of new comm link and delivery path
  - Improved spatial reuse and reduced energy consumption by lowering Tx power level
- **Side effects**
  - New asymmetric/ weak links might be generated => **Power Control + Blacklisting**
  - More energy consumption/ Interference at amplified Tx power level.

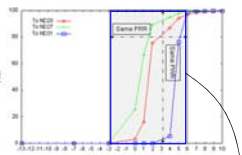
Problem Description: Dynamic link quality and the effects of Transmission power variation

Systematic Experiments (with all x-axis as Tx power)

Reliability as a function of Tx and Rx hardware and Distance

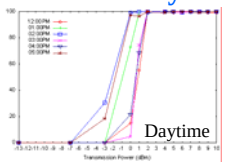

Tx h/w change at 14m

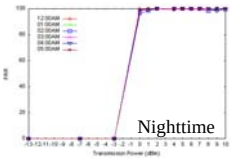

Tx h/w change at 23m


Rx h/w change at 23m

- Conspicuous difference cause by h/w in low SNR situation (≥17m)
- Different level of Tx power required to reach the same level of link reliability

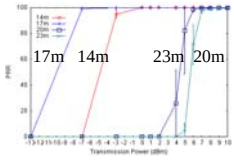
Reliability as a function of Time



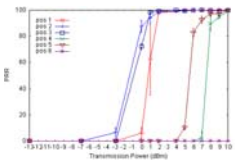


- Surrounding environment change causes a link quality variation
- Outside of UTPR (at 2dBm): the link is converted to a good link

Reliability as a function of Link Distance and Node Location



Four different link distances


Six different close node locations

- Non-linear link quality to the link distance change
- Small change in environment or Tx power may cause significant difference in link quality (severe multipath effects at indoor env)

- **Unreliable Tx Power Range (UTPR)**
  - Transmission power range where link qualities are dynamic between different links at the same distance or where link qualities are dynamic for the same link
- **Observations: Variations in link quality**
  - Dynamic link quality and link availability can be controlled with Tx power control
  - Blacklisting is necessary to remove remaining unreliable links after the power control

Proposed Solution: Transmission Power Control with Blacklisting (PCBL)

Characteristics of PCBL

- Adjust transmission power to control link quality
- Control transmission power on a packet basis
- Estimate link quality based on packet reception (PRR) metric
- Blacklist unreliable links at adjusted transmission power level
  - Either link-based and packet-based blacklisting.

Basic PCBL Algorithm (w/o optimization)

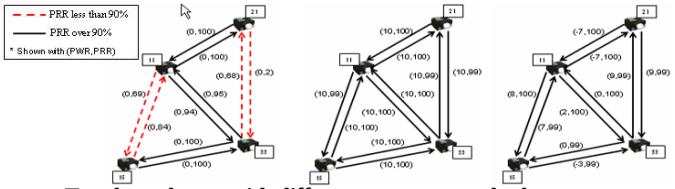
1) Collect Link Statistics in PRR metric
2) Select a Unicast Tx power for each link (based on link quality threshold)
3) Blacklist unreliable links (based on blacklisting threshold)
4) Select a Blacklist Tx power for each node

* To deal with dynamics, these steps can be repeated at pre-selected intervals

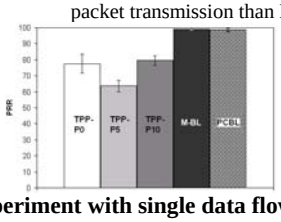
Experiment Details

- **Tested Power Control Schemes**
  - TPP-Px : Two Phase Pull at xdBm Tx power for every node
  - M-BL : TPP with blacklisting at the maximum Tx power allowed
  - PCBL : Our proposed Tx power control scheme with blacklisting
- **Experiment methodology**
  - Routing Protocol: Directed diffusion (Two-Phase-Pull)
  - MAC protocol: S-MAC in fully active mode
  - Experiments are repeated five times for each scheme

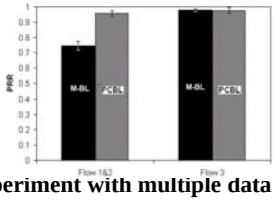
Experimental Comparison of Schemes



- **Topology change with different power control schemes**
  - Each link is marked with (Tx power, PRR) information
  - PCBL shows equivalent link qualities with lower energy consumption for packet transmission than M-BL



- **Experiment with single data flow**
  - Amplifying Tx power equally for every node was not helpful
  - PCBL and M-BL results in best PRR



- **Experiment with multiple data flow**
  - M-BL shows reduced PRR in multi-flow experiments due to some queue overflows
  - PCBL shows better spatial reuse

Conclusions

- **Experiment study shows the causes of high link quality variance and the effects of transmission power control on dynamic link quality control**
- **Tx Power control with Blacklisting provides an effective link quality control**

Paper with more details : D. Son, B. Krishnamachari, and J. Heidemann, "Experimental study of the effects of Transmission Power Control and Blacklisting in Wireless Sensor Networks", IEEE SECON, October 2004.