Optimized Multipath Streaming in ZigBee WSNs

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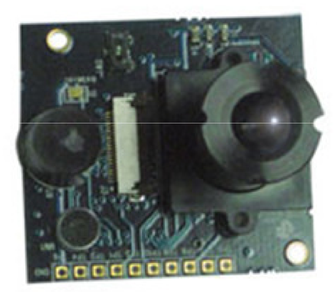
Wireless Sensor Networks

Wireless Sensor Networks (WSNs) are

- Ad-hoc, multi-hop networks comprised of small, simple, and inexpensive wireless devices
- Nodes are responsible for sensing an environment and reporting their results to a central unit known as the sink
- Small size of nodes implies constrictions in processing speed, memory, and energy



WSNs in the real world

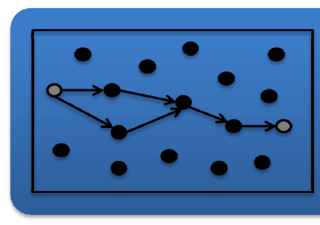
- Parking space monitoring, fire protection, and home automation
- Video/audio based home surveillance
- Target tracking

With the increasing availability and decreasing cost of sensor nodes equipped with cameras and microphones,the number and range of WSN real-time data streaming applications is expected to grow in the near future.

Multipath Routing

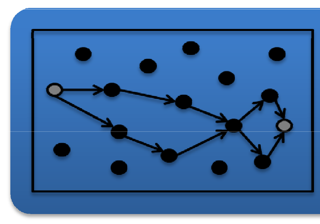
Multipath routing is the routing technique of leveraging multiple alternative paths through a network, which can yield a variety of benefits but not without challenges to overcome.

Multipath Formation Strategies



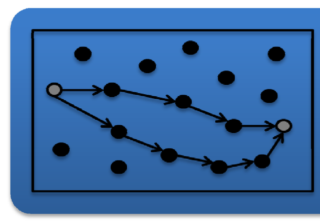
Partially-disjoint Paths Strategy

- allows each of the chosen paths to share one or more nodes with any of the other paths



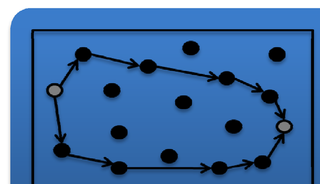
Edge-disjoint Paths Strategy

- precludes each chosen path from sharing any edges with any of the other paths



Node-disjoint Paths Strategy

- precludes any two chosen paths from sharing one or more nodes with each other



Zone-disjoint Paths Strategy

- requires that each chosen path be node disjoint and not be within the interference range of other chosen paths as much as physically possible

Multipath Usage Strategies

- ***Consecutive Data Transmission*:** Data is initially sent along a *primary* path, and only in the case that the primary path fails, alternate paths are used.
- ***Concurrent Data Transmission*:** Data is divided and sent along each of the multiple paths at the same time.

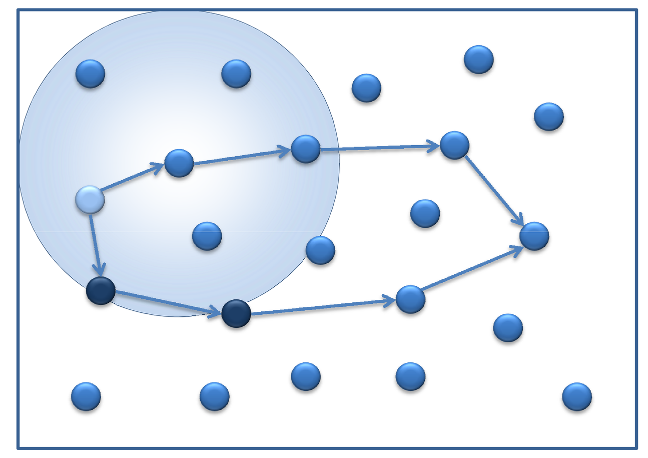
Benefits of Multipath Routing

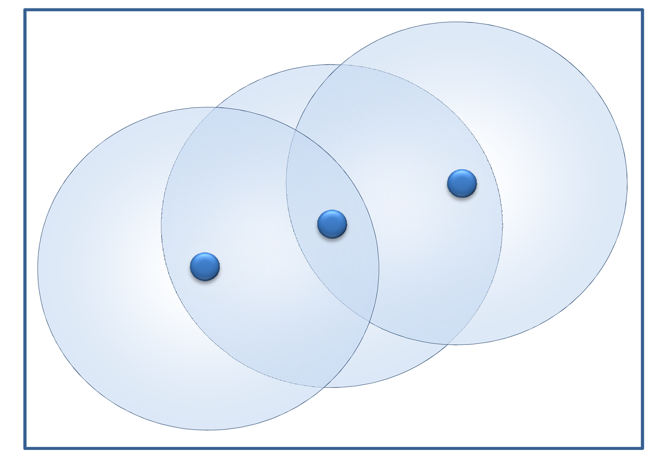
- Increases ***reliability*** by finding multiple paths from a source to a destination and using them as backup paths on the detection of a route failure.
- Provides ***security*** by dividing data into multiple segments and propagating them through many geographically separated paths, making it difficult for an adversary to eavesdrop on the communications.
- Reduces ***end-to-end*** delay and increases ***throughput*** by using concurrent data transmission to divide traffic along multiple paths thus spreading the stress throughout the network.
- Balances ***load*** and ***energy*** consumption by including more nodes through the use of multiple paths to route traffic from a source to a destination.

The Challenges of Multipath Routing in the Wireless Domain

The broadcast nature of the communication medium poses some problems in the context of multipath routing

- ***Intra-path interference*** is the radio interference among the nodes that belong to the same routing path.
- ***Inter-path interference*** is the radio interference between nodes belonging to different routing paths.
- ***Hidden Terminal Problem*** is a situation where collisions occur from two nodes that cannot sense each other sense the medium to be free and attempt to send a packet thus causing a collision to occur at the third node in the middle.





Interference Modeling

Motivation

We aim to maximize throughput by mitigating the negative effects caused by interference. By assuming a Semi-TDMA transmission schedule we attempt to maximize the number of concurrently transmitting nodes in the network while maintaining a level of interference that is acceptable. To accomplish this 3 conditions must be satisfied.

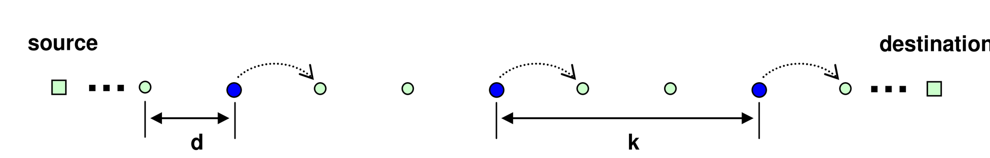
Parameters Affecting Performance

- ***Noise and Interference (NI) and the Energy Detect Threshold (ED)***
  - For a node not to block itself from beginning a transmission the *NI* arriving at its receiver must be below *ED* when determining if the channel is busy
- ***Received Signal Strength (RSS) and the Minimum Transmission Power Threshold (MP)***
  - For a node to begin the reception of a packet the transmitting node must use a transmission power that is strong enough to produce a *RSS* above the *MP* threshold
- ***Signal to Noise and Interference Ratio (SINR) and the Bit Error Rate Threshold (BER)***
  - For a node to successfully receive a packet sent to it the *SINR* level must be sufficient to produce fewer bit errors in the packet than required by the *BER* threshold

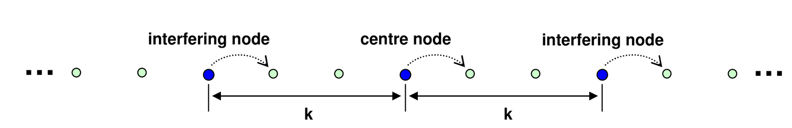
Linear Network

We first model intra-path interference in a linear network to determine how to satisfy all of the conditions.

- Network Configuration (*N* nodes spaced *d* meters apart and concurrently transmitting nodes *k* hops apart)

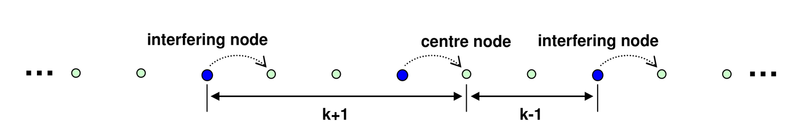


- Noise and Interference (Calculated at the Sending Node)



$$NI = 2 \cdot \sum_{i=1}^{\frac{\lfloor (N+1)/k \rfloor - 1}{2}} \frac{P_t}{\left(\frac{4 \cdot \pi \cdot f \cdot ikd}{c}\right)^a}$$

- Signal to Interference and Noise Ratio (Calculated at the Receiving Node)



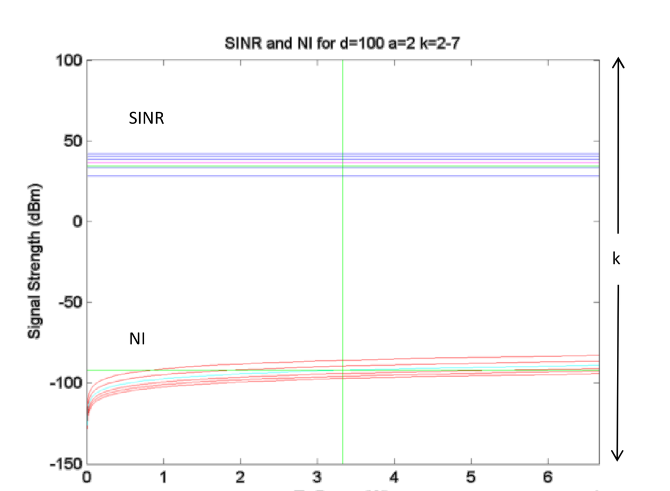
$$SINR = \frac{1}{\left(\sum_{i=1}^{\frac{\lfloor (N+1)/k \rfloor - 1}{2}} \frac{1}{(i \cdot (k+1))^a} + \frac{1}{(i \cdot (k-1))^a}\right)}$$

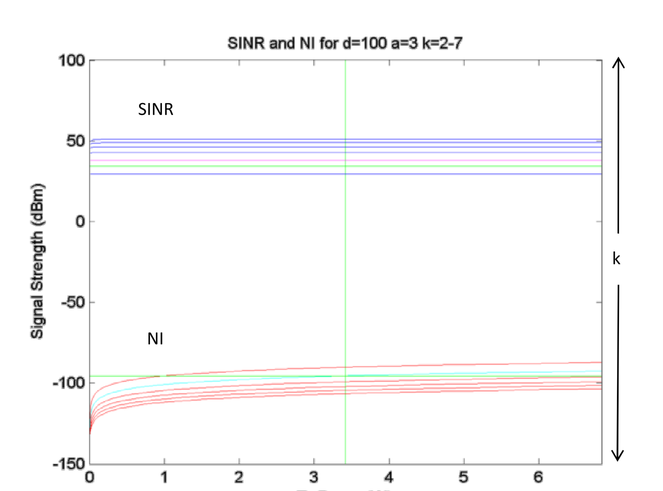
- Minimum Power

$$MP_t = MP \cdot \left(\frac{4 \cdot \pi \cdot f \cdot d}{c}\right)^a$$

Optimal *k* Spatial Separation

We plot *NI* and *SINR* and the thresholds for various values of *k* to determine the minimum *k* required (i.e. minimal spatial separation) between concurrently transmitting nodes to obtain a network configuration that is stable in order to maximize throughput.



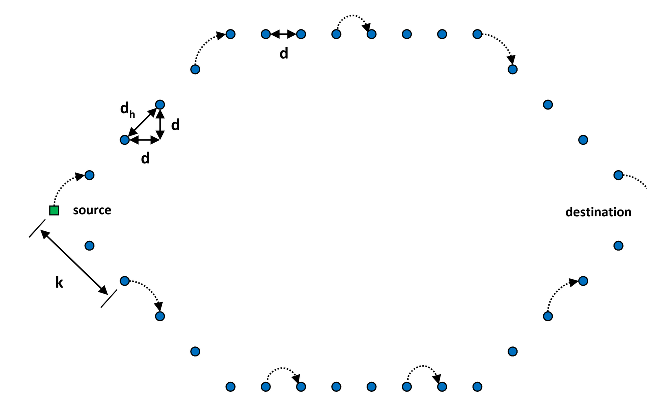


For a path loss exponent (a) of 2 the optimal node separation (k) is calculated to be 4 while for a path loss exponent of 3 concurrently transmitting nodes can be spaced only 3 hops away.

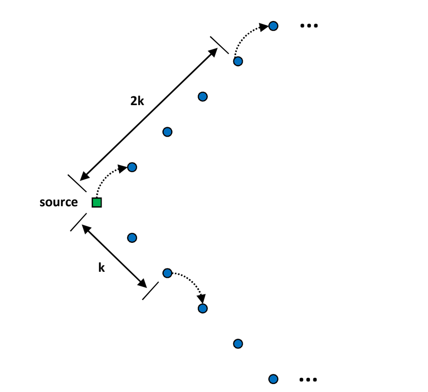
Multipath Network

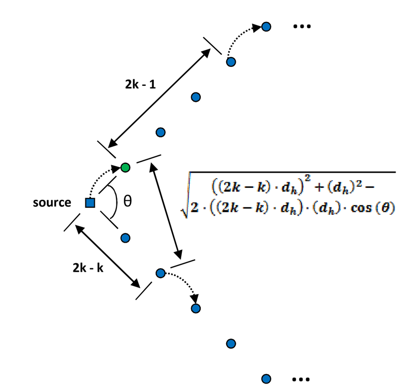
Next, we model both types of interference in a zone disjoint multipath network to determine how to satisfy all conditions. Zone disjoint multipath routing is the best routing algorithm for use since it has been shown to mitigate interference best [1]. Traffic is equally divided amongst the two paths.

- Network Configuration



- Multipath Noise and Interference (Calculated at the Sending Node) and Multipath Signal to Interference and Noise Ratio (Calculated at the Receiving Node)





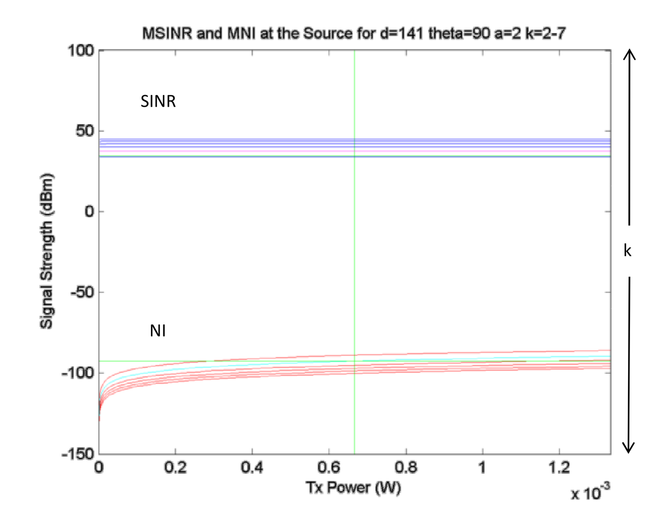
$$MNI = \left(\sum_{i=1}^{\lfloor (N/k)/2 \rfloor} \frac{P_t}{\left(\frac{4\pi \cdot (kid_h) \cdot f}{c}\right)^a}\right) + bgn$$

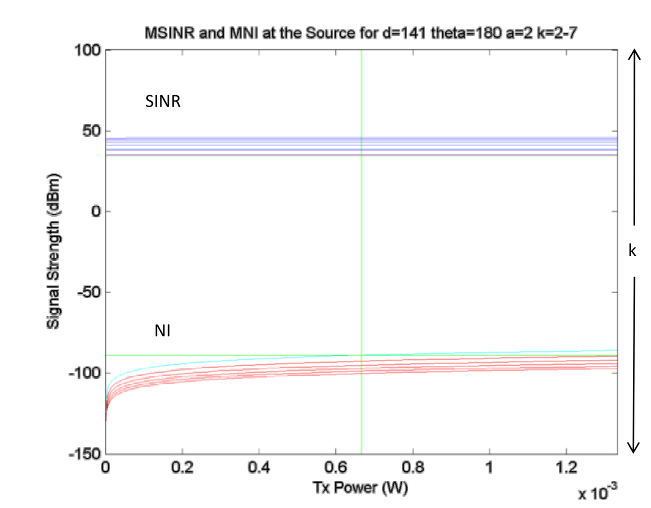
$$MSINR = \left(\frac{(d_h)^{-a}}{\sum_{i=1}^{\lfloor (N/k)/4 \rfloor} ((2k \cdot i - 1) \cdot d_h)^{-a} + \left(\sqrt{((2k \cdot i - k) \cdot d_h)^2 + (d_h)^2 - 2 \cdot ((2k \cdot i - k) \cdot d_h) \cdot (d_h) \cdot \cos(\theta)}\right)^{-a}}\right) + bgn$$

- Minimum Power remains the same as the linear network configuration

Optimal *k* Spatial Separation

We plot *MNI* and *MSINR* and the thresholds for various values of *k* to determine the minimum *k* required between concurrently transmitting nodes in a multipath configuration. It is observed that the minimal *k* here varies based on the angle of separation between the paths and is *smaller than the linear network*.

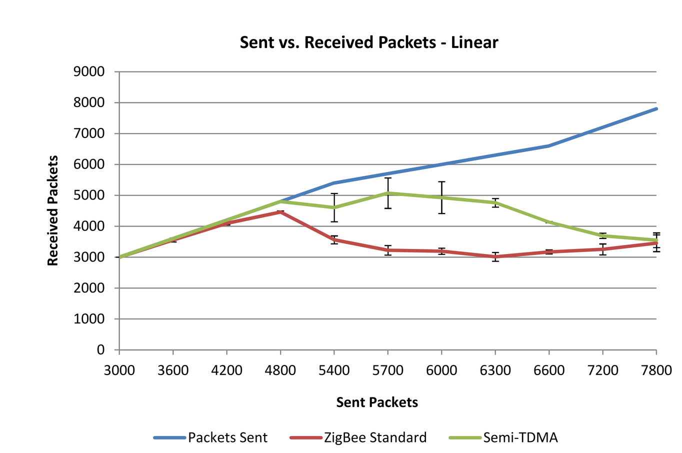


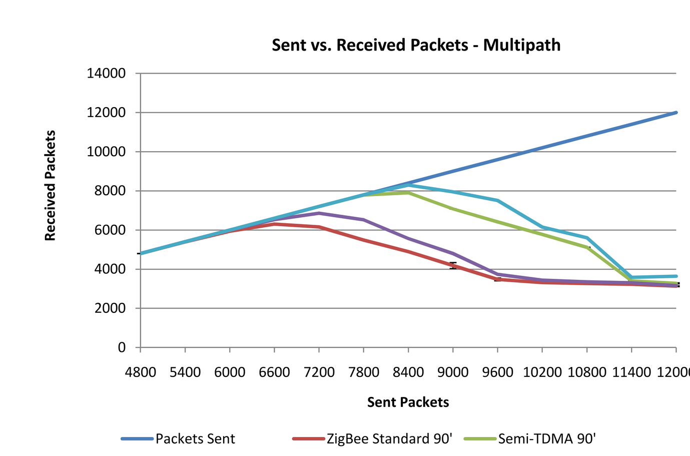


For a ϑ of 90 degrees the optimal node separation (k) is calculated to be 3 while for a ϑ of 180 degrees concurrently transmitting nodes can be spaced only 2 hops away.

Simulations

We conduct simulations in OpNET Modeler of both linear and multipath networks and demonstrate that the multipath network which allows for a smaller spatial separation between concurrently transmitting nodes (i.e. smaller *k*) is more robust to higher data rates. Specifically in the linear network performance peaks at 40 pkts/s while in the multipath network a data rate of 70 pkts/s is required to reach peak performance.





[1] Spanogiannopoulos, G., Vlajic, N., & Stevanovic, D. (2009). A Simulation-Based Performance Analysis of Various Multipath Routing Techniques in ZigBee Sensor Networks. *ADHOCNETS 2009* (pp. 1-16). Niagara Falls, Canada: Springer LNICST.

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