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Low Energy Bluetooth Inter-Node Communication Schemes via Randomized Reconfiguration

Chengtao Xu and Dr. Vincent Winstead PH.D.

Department of Electrical & Computer Engineering & Technology

Xcel Energy®

Big ideas. Real-world thinking.

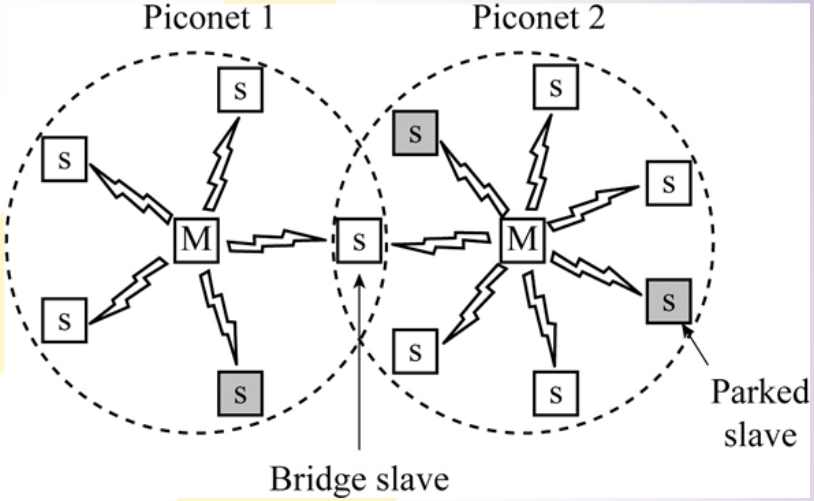
Presentation Outline

- Introduction to research problem
- Low Energy Bluetooth (BLE) communication model
- Two communication schemes
- Randomize Reconfiguration
- Simulation Results
- Conclusion

What is BLE?

$P_{bluetooth} = 1\ W > P_{BLE} = 0.01 \sim 0.5\ w$

BLE Topology

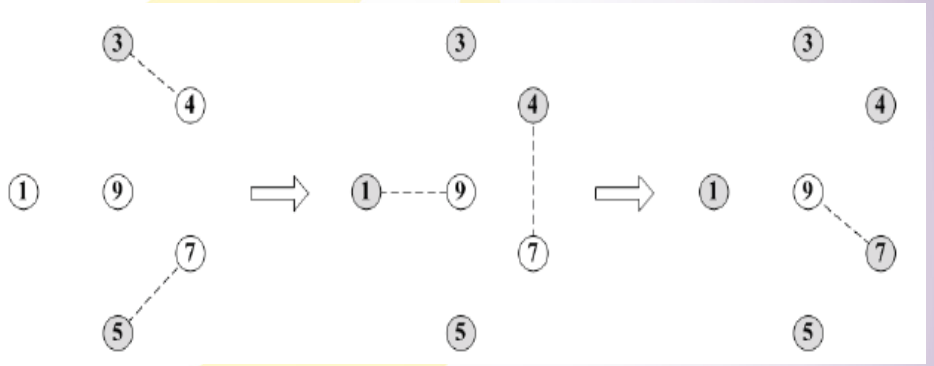


WiFi

BLE

BLE Scatternet Formation

```
NodeDiscovery(){
1. S = Ø;
2. M = Ø;
3. startTimer(T);
4. while( T< Tmax ){
5.       neighbor = Advertise();
6.       if (neighbor  ≠ Ø)
7.            M = M ∪ neighbor;
8. }
9. startTimer(T);
10. while( T< Tmax ){
11.      neighbor = Scan();
12.      if (neighbor  ≠ Ø)
13.           S = S ∪ neighbor;
14. }
```



Node discovery in single piconet formation

BLE Scatternet Formation

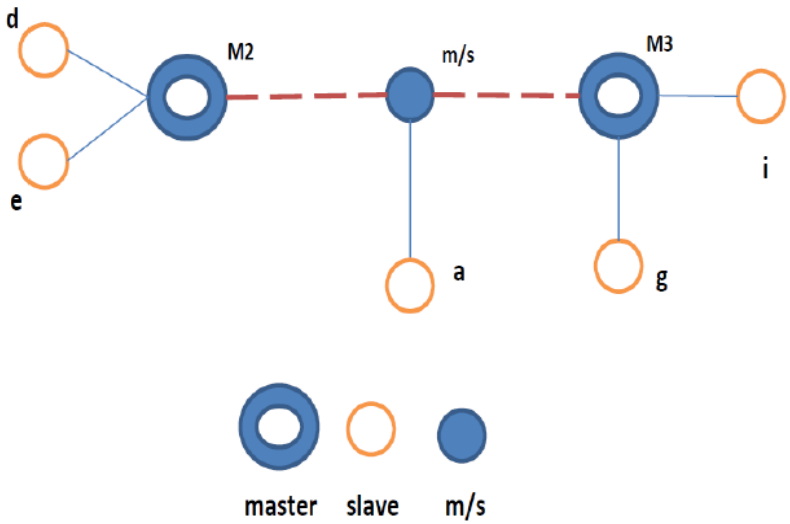
Nodes	Roles
s	slave
e	slave
a	slave relay
r1	m/s relay

a) M2's slave list

Nodes	Roles
M2	master in piconet M2
M3	master in piconet M3

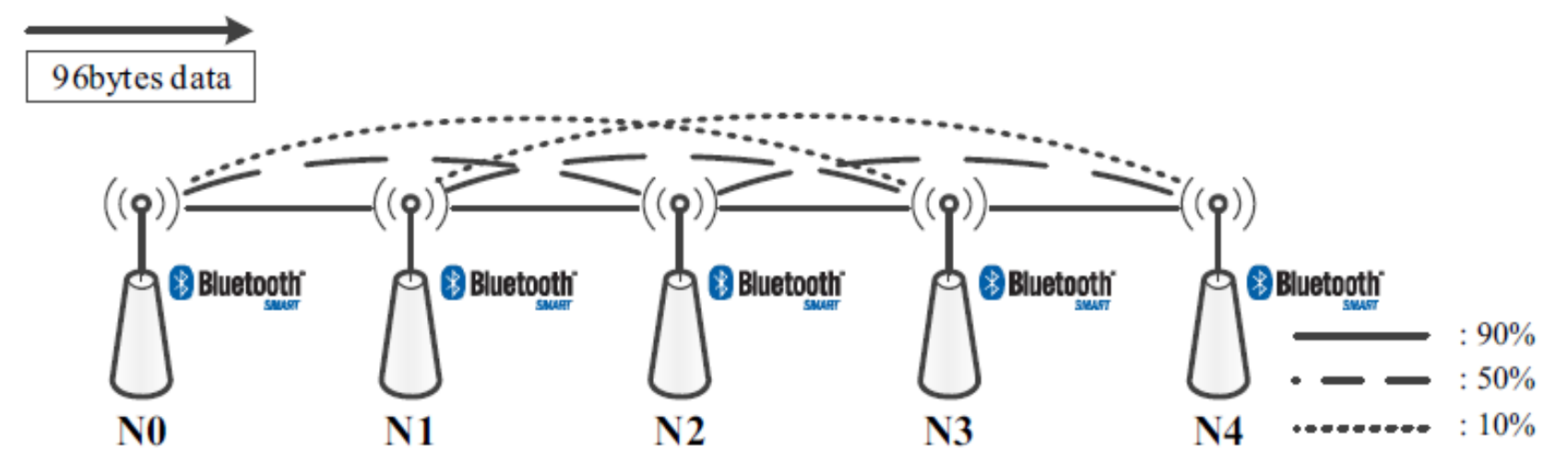
b) R1's master list

Neighbor lists



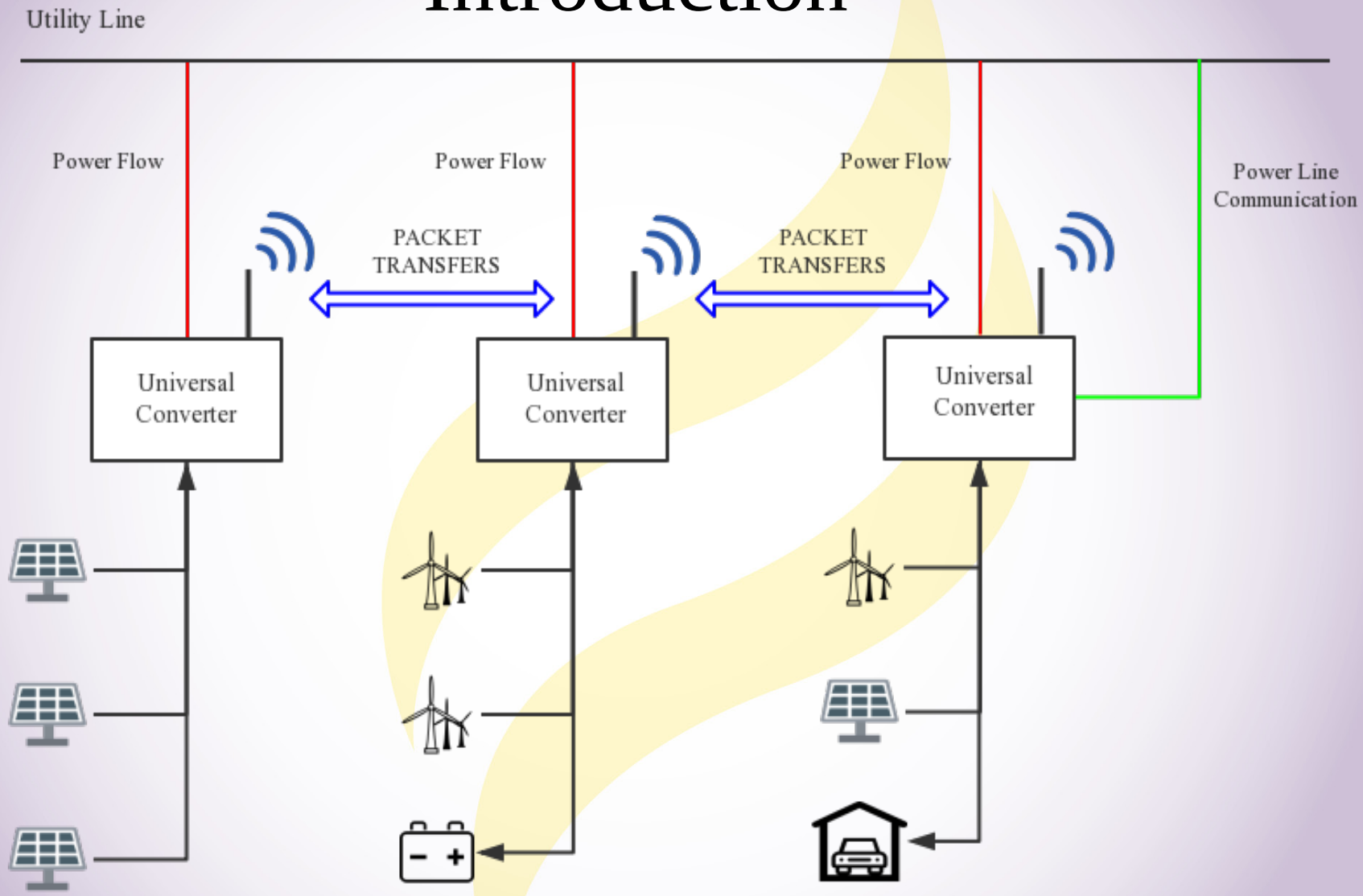
BLE topology

BLE Communication Latency



Sample network latency

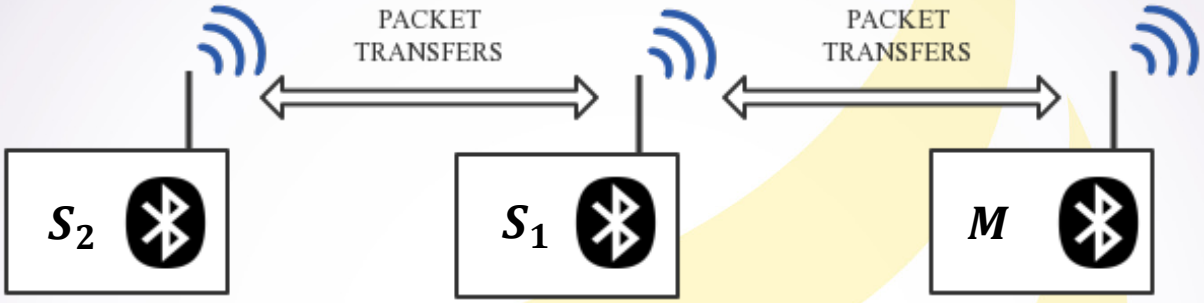
Introduction



Research Problem

- How to use less power consumption to realize the wireless communication networks in this universal converter system?
- How to choose the right communication scheme minimize the transition latency to reach the destination of the master device?

Communication System Model



Assumption:

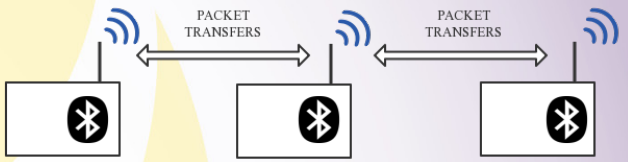
- Assume the communication packets are of a uniform length and content.
- All nodes require same communication capability with same transmission latency T_{tx} , which is not include the discovery latency.
- Similarly, all nodes are assumed to have the same power flow data capture capability leading to a constant latency for data capture T_d .
- $T_d > T_{tx}$.

Asynchronous Scheme

- All nodes broadcast power flow data periodically:

$$T = T_d + T_{tx}$$

$$T_{tx} = \alpha \cdot T_d \, , \alpha \in (0,1)$$



- The likelihood of collisions among adjacent nodes:

$$\frac{2 \cdot T_{tx}}{(1+\alpha)T_d} = \frac{2 \cdot \alpha \cdot T_d}{(1+\alpha)T_d} = \frac{2 \cdot \alpha}{(1+\alpha)}$$

- A minimum time from all nodes transfer through the network to master node with N total nodes in this networks:

$$(N-1) \cdot T_{tx}$$

Synchronous Scheme

- Slave i receives a data request at time t_i. The slave node i transmits data back at time $t_i + T_d$. Node remain in server mode between $t = t_i$ and $t = t_i + T_d$.

$$t_i + T_d$$

- When $T_{tx} \ll T_d$, the total transmission time is:

$$2 \cdot (N - 1) \cdot T_{tx} + T_d$$

Comparation Between Two Schemes

- The total transport time of synchronous scheme is longer than expected asynchronous scheme.

$$2 \cdot (N-1) \cdot T_{tx} + T_d > (N-1)T_{tx}$$

- The asynchronous scheme is likely to experience additional re-transmission delays due to collision.

- For each re-transmission delay, the asynchronous scheme has $2 \cdot T_{tx}$ within the period T .

Randomize Reconfiguration

- An uniformly distributed offset is applied.

$$t_0 \sim T_{tx} \cdot U(-1,1)$$

- The mean of this offset is zero, so the aggregate additional network data transfer delay is zero.
- The likelihood of collision happens in asynchronous scheme increase the data transfer latency.

$$\frac{2 \cdot \alpha}{1 + \alpha} \cdot (N - 1) \cdot T_{tx}$$

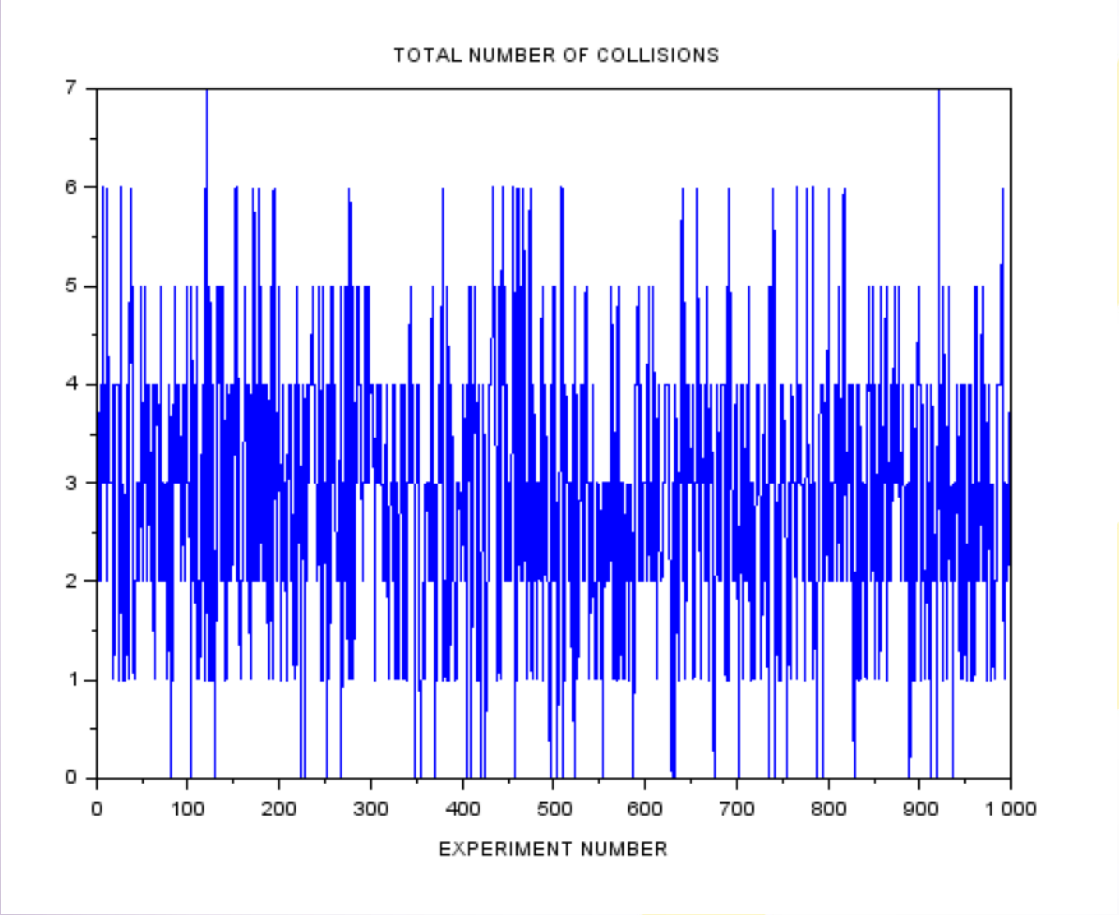
Simulation Results

- Given that any independent collision happens in each time period, the additional T_{tx} can be added for each transmission process.

- The minimum expected mean latency is

$$(N-1)\cdot T_{tx}\cdot\left(1+\frac{2\cdot\alpha}{1+\alpha}\right)=0.12$$

Total Number of Collisions



Total number of collision for each node of 1000 experiments

Mean Latency of Simulation

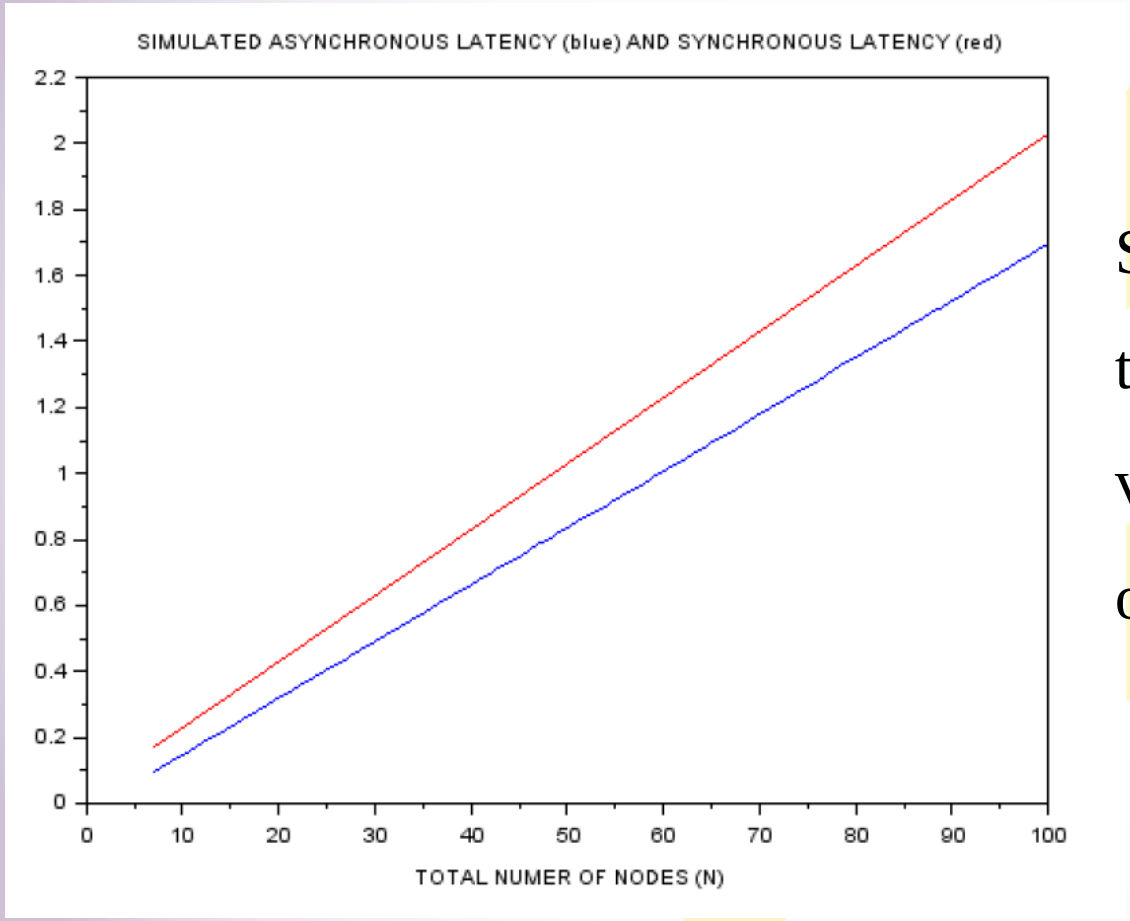
- The mean latency of simulation is computed as

$$L_m = (N-1)\cdot T_{tx} + \frac{\sum_{j=1}^{n} \sum_{i=0}^{n_c^j} 2 \cdot T_{tx}}{n}$$

$$= (N-1)\cdot T_{tx} + \frac{\sum_{j=1}^{n} n_c^j \cdot 2 \cdot T_{tx}}{n}$$

- $L_m = 0.23668$ exceeds the minimum expected mean latency.

Latency of Two Schemes



Simulation results using the two schemes with N varying from seven to one hundred nodes

Future Works

- The experiments will be performed using LowE-BT based platform and testing how physical interference affects the transmission quality and latencies by applying two schemes.

- The way how transmission latencies can have side effects on power flow data transfer.

Thank you for listening !