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Low-Latency Smart Grid Asset Monitoring for Load Control of Energy-Efficient Buildings

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Outline

- Introduction
- Priority and Delay Aware Medium Access in WSNs
    - Delay Estimation
    - MAC Layer Configuration
- Performance Evaluation
- Conclusions

Introduction(1)

- WSNs offer many advantages;
  - Ability to work in extreme environmental conditions
  - Enhanced fault tolerance
  - Low power consumption
  - Self configuration
  - Low cost

- WSNs have low data rate and limited energy resources
  - Performance bottleneck
  - Delivery of time-critical data becomes a significant challenge
- Thus data prioritizing techniques becomes essential in WSNs

Introduction(2)

- **In the smart grid, a fault occurring in any of its assets may trigger load control actions in various locations.**
- **The status of the smart grid assets needs to be monitored in near real-time.**
- **Transmitting delay-critical data in the smart grid via WSNs needs data prioritization and delay-responsiveness.**
- **We evaluate the performance of two schemes,**
  - **Delay-responsive, cross layer (DRX) data transmission scheme**
  - **Fair and delay-aware cross layer (FDRX) data transmission scheme**

Priority and Delay Aware Medium Access in WSNs (1)

- Delay Estimation
  - Estimate the delay using an analytical model of the slotted CSMA/CA mechanism of IEEE 802.15.4
  - The model is based on a WSN having a PAN coordinator with *N* nodes
  - Each node uses beacon-enabled mode
  - The model uses Markov chain to model the behavior of a single node
  - The main idea behind the model is that
    - Sensor nodes can estimate the busy channel probabilities
    - Depending on first and second CCA's.

Priority and Delay Aware Medium Access in WSNs (2)

- MAC Layer Configuration
  - DRX scheme includes a data prioritization cross layer adaptive scheme
  - FDRX scheme includes an improvement to the DRX scheme
  - Both DRX and FDRX scheme enables the interaction of the application layer with the MAC and physical layers of the IEEE80.15.4 protocol stack
  - DRX achieves more aggressive delay reduction in highly critical smart grid monitoring applications.
  - FDRX scheme achieves the delay reduction and allow other nodes to transmit in a timely manner.

Fairness in Delay-aware Cross Layer Data Transmission Scheme (FDRX) (3)

- Both the DRX and the FDRX schemes initially implements the delay-estimation algorithm
- The MAC layer responds to the delay requirement of the application
- If the estimated delay is found higher than a predefined threshold
  - The application layer inserts a flag indicating that lower layers should treat the packet accordingly
  - The MAC layer makes changes to the parameters of the physical layer
- DRX changes the CCA duration for the entire session
- The FDRX schemes yields to other nodes periodically to allow them to transmit

Fairness in Delay-aware Cross Layer Data Transmission Scheme (FDRX) (4)

- The algorithm is implemented as follows;
  - Application layer evaluates criticality of the captured data
  - The algorithm invokes the delay estimation process
  - In DRX, the CCA duration is divided by 2 for the entire beacon interval
  - In FDRX, the CCA duration is divided by 2 for duration of η_y and then inverts back to default setting for the next η_y duration
  - If the estimated delay is within allowable limit of a particular application
    - The algorithm does not make any changes in the MAC or physical layer parameters

Performance Evaluation

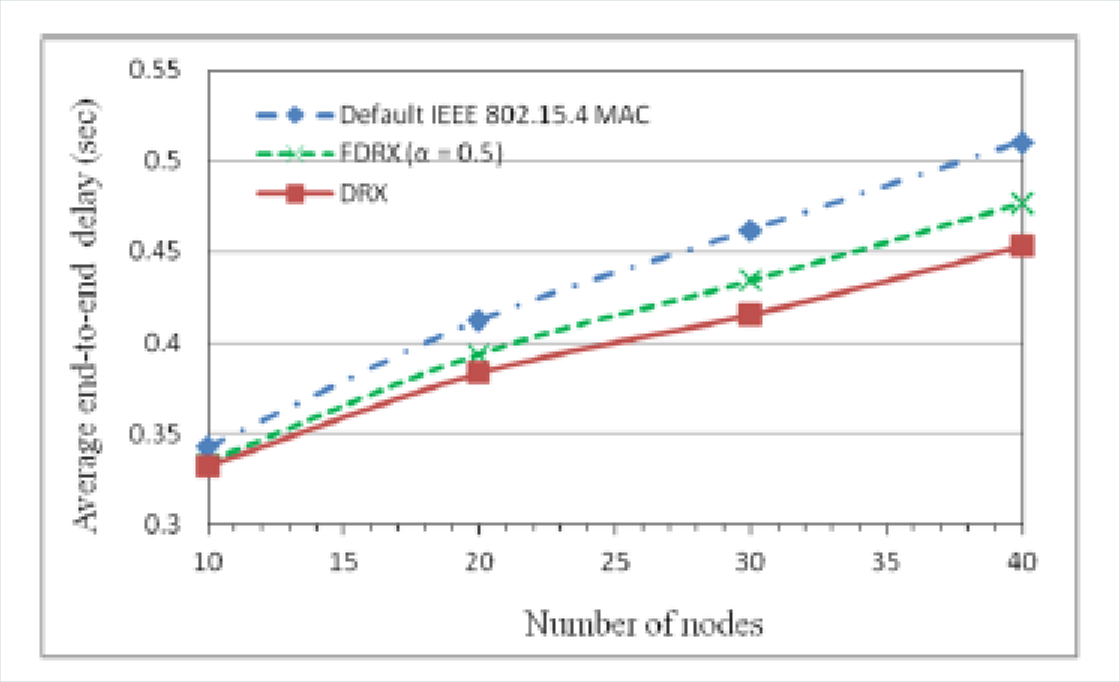
- We use QualNet network simulator
- We use a star topology having *N* nodes and a coordinator
- All nodes are operating in the 2.4 GHz band with a maximum bit rate of 250 Kbps
- The transmission range was set to 40m and all the nodes are in the same PAN
- Each result represents an average of 10 runs

Performance Evaluation

TABLE II
ACTUAL CHANNEL PROPAGATION PARAMETERS

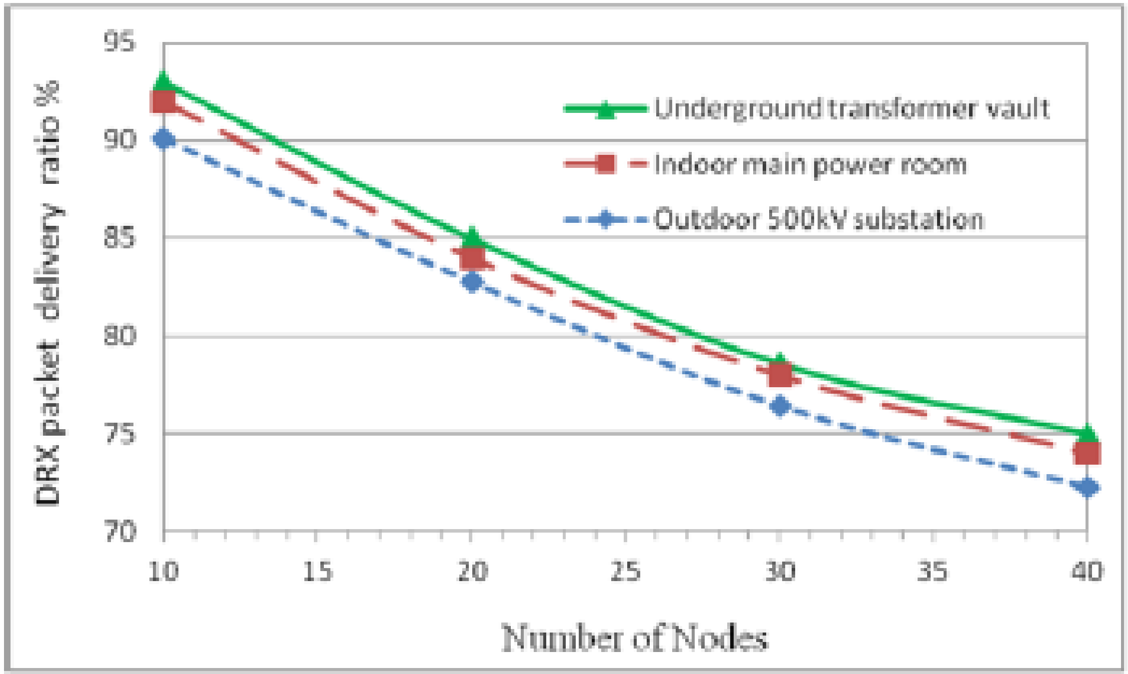
Propagation Environment	Path loss	Shadowing deviation
Outdoor 500-kV substation	3.51	2.95
Indoor main power room	2.38	2.25
Underground transformer vault	3.15	3.19

Performance Evaluation



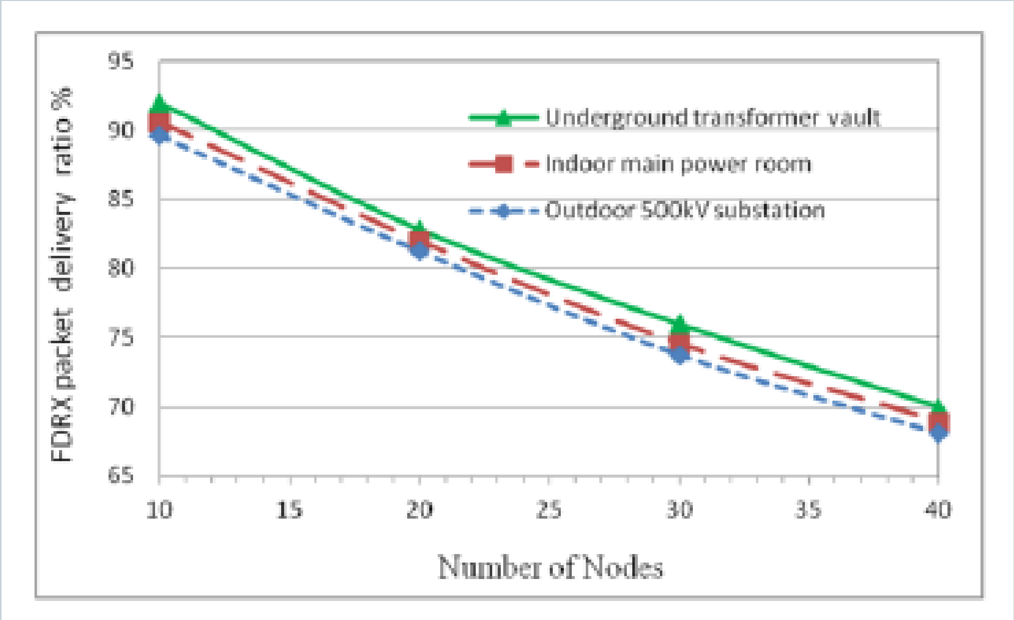
Average end to end delay

Performance Evaluation



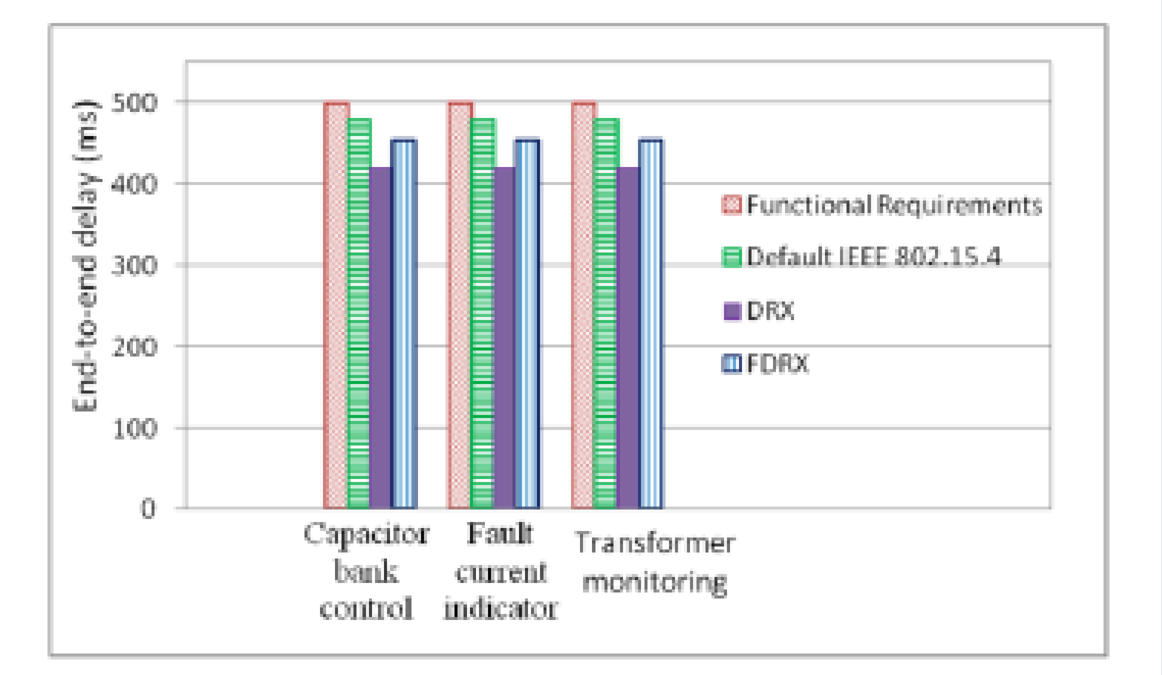
Data delivery performance of DRX

Performance Evaluation



FDRX packet delivery ratio

Performance Evaluation



End-to-end delay for different smart grid applications.

Conclusions

- The presented schemes achieve delay-responsiveness by modifying the parameters of the physical layer of the IEEE 802.15.4 protocol.
- DRX and FDRX schemes succeed in reducing the delay for high priority data and maintaining satisfactory packet delivery ratios.
- Smart grid specific results show that the DRX scheme has a higher effect on the end-to-end delay reduction compared to the FDRX.
- FDRX shows more flexible results and provides fairness to other nodes in the WSN.
- This delay reduction will enhance the smart grid operation in situations where sudden changes in loads or the generation cycle

THANK YOU !