System Control Applications of Low-Power Radio Frequency Devices

Roger van Rensburg, Bruce Mellado and Charles Sandrock

School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa

Abstract

- A low-power wireless network is under development for application deployment to reduce theft of computer devices used in educational institutions. The goal is to develop a reliable network that can restrict the accessibility of a device visual interface. A device may request regular updates using a polling algorithm to a mesh router network. When a tablet is operated in a field perimeter where communication in the network is unavailable, a shutdown of the device operating system may be initiated that render the device unusable. By incorporating one of the latest mesh wireless technologies, an anti-theft system may be implemented that has the potential to reduce major tablet theft in institutions of digitized learning. Results indicate reliable performance of data communications between interconnecting nodes using the Thread networking protocols.

Methodology

- Development of a low-power ad-hoc Wireless Sensor Network (WSN).
- Radio frequency propagation modeling in an indoor building environment.
- Point to point field measurements and modeling to determine performance and reliability of network. Statistical approach followed in data analysis.

Network Topology

- Nordic Semiconductor: nRF52840 System-on-Chip (SoC).
  - SoC: Low-power integrated MCU and 2.4 GHz radio (IEEE 802.14.5).
  - 32-bit ARM cortex-M4F MCU, 64 MHz clock, 1 MB flash and 256 kB of RAM.
  - Run multiprotocol stacks concurrently: Bluetooth Low Energy, ANT, ZigBee and IPv6 based Thread networking protocol.
  - Application layer: COAP or UDP messaging between nodes.

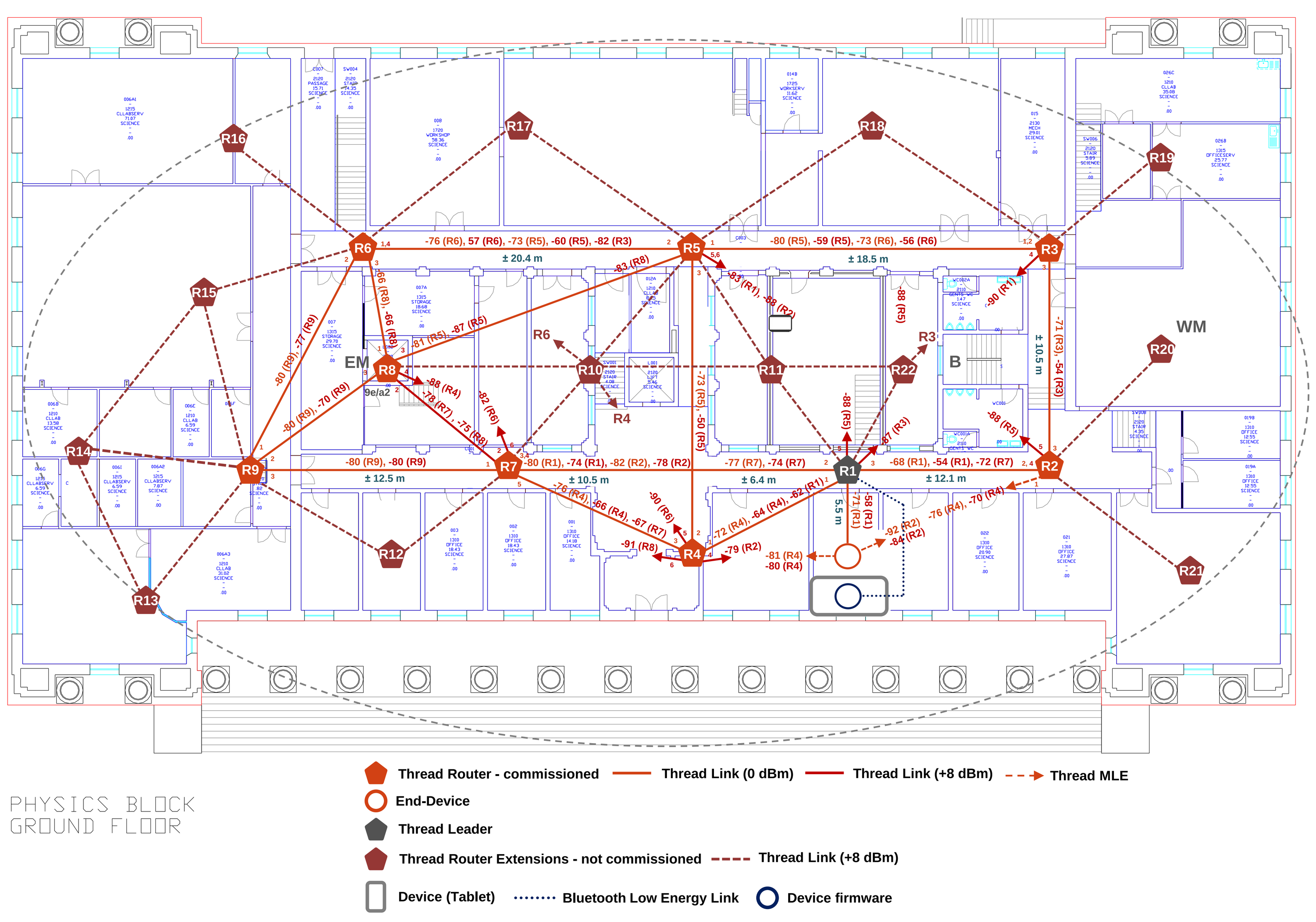

Figure 1: Experimental WSN development.

- **Fig.1** illustrate the mesh WSN developed at the Wits physics building ground floor. A Thread network allows up to 32 routers and 511 end-devices per router depending on SoC memory specifications [1].
  - Commissioning of one end-device and nine routers (R1-R9).
  - One leader in network. Controls addressing and topology changes.
  - Each end-device has a parent router that operates at low duty cycles.
  - No single point of failure. If leader fails, another router is selected as leader.
  - Network may connect to WiFi and Ethernet using a border router.
  - Mesh Link Establishment (MLE) discovery data to determine the wireless mesh topology depicted in **Fig.1** at 0 and +8 dBm respectively.
  - MLE periodically sends multicast messages to estimate the quality of links of each neighboring router in the network.
  - Distance vector routing and trickle algorithm [1].

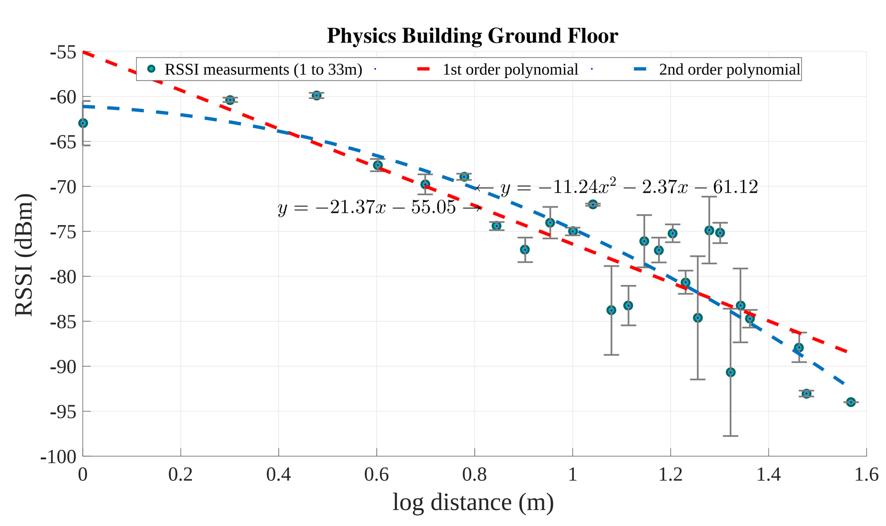

Figure 2: RSSI vs log10(d) at Tx = 0 dBm.

- **Fig.2** illustrate the log distance path loss Model: $\boldsymbol{RSSI = 10n\log_{10}(d) + A}$.
  - Receive Signal Strength Indicator (RSSI) between two nodes [2].
  - Path losses are signal attenuation of electromagnetic wave propagation.
  - where $\boldsymbol{n}$ is the path loss exponent, $\boldsymbol{A}$ is an environmental constant and $\boldsymbol{d}$ is the distance between the nodes in meters.
  - Path loss exponent is estimated using polynomial least-squares regression.
  - Distribution and localization of nodes in an indoor environment.

Results

- Internet control message protocol requests were sent at 80 bps from end-device to router where latency measurements were recorded.
- Statistical approach followed whereby distributions of the latency measurements were computed in order to visualize the performance of the network.

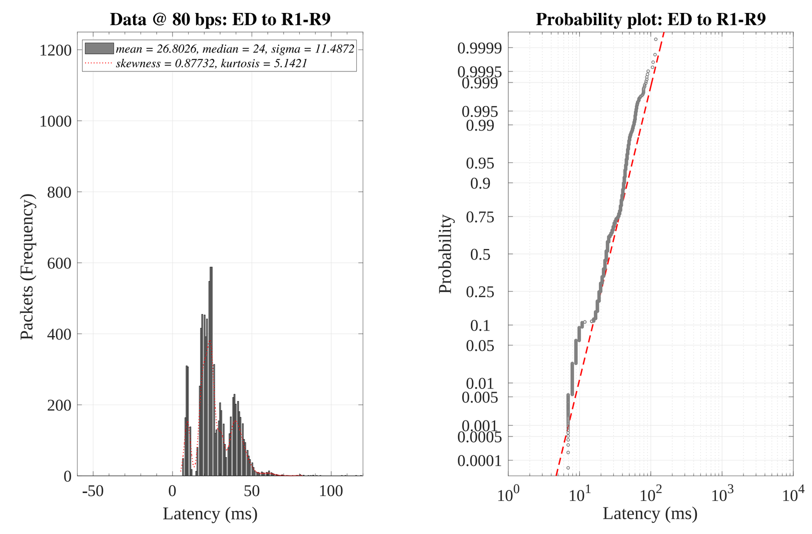

Figure 3: Distribution at Tx = 0 dBm.

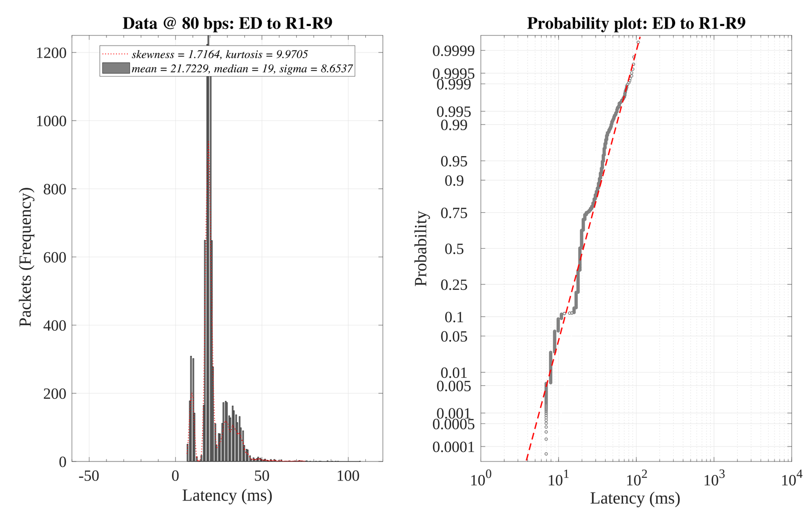

Figure 4: Distribution at Tx = +8 dBm.

- In **Fig.3** and **Fig.4**, latency measurements from ED to R1 through to R9 are combined in a single data vector. Latency and the probability distribution are plotted at Tx = 0 dBm and Tx = +8 dBm respectively.
  - Multimodal distribution and skewed right.
  - Higher latency delays, jitter and packet losses in shadowing areas.
  - Outliers may be caused by CSMA-CA retransmissions, substandard link quality or packet relays/transmissions over greater mesh multi-hopping distances.
  - **Fig.3** reveal a 99 % CI of $\boldsymbol{\mu = 26.80 \pm 0.31}$ and $\boldsymbol{\sigma = 11.49 \pm 0.22}$.
    - 0 dBm: 1 % probability that latency is $\geq$ 60 ms.
  - **Fig.4** reveal a 99 % CI of $\boldsymbol{\mu = 21.72 \pm 0.2357}$ and $\boldsymbol{\sigma = 8.66 \pm 0.17}$.
    - +8 dBm: 1 % probability that latency is $\geq$ 50 ms.

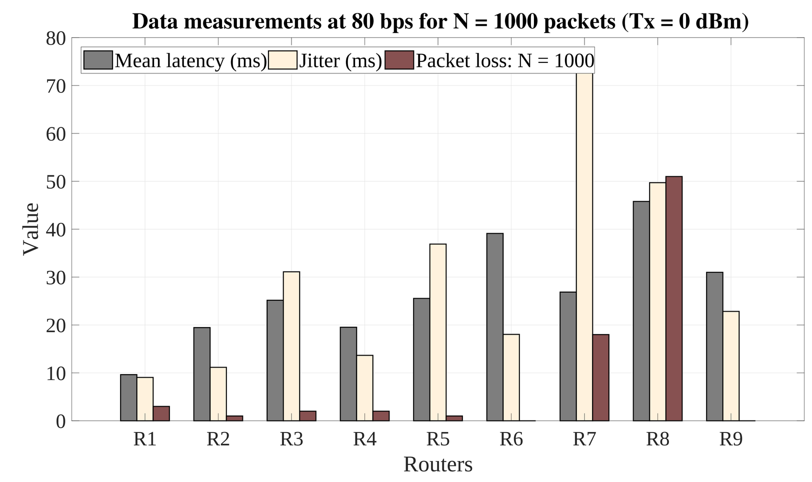

Figure 5: WSN performance at Tx = 0 dBm.

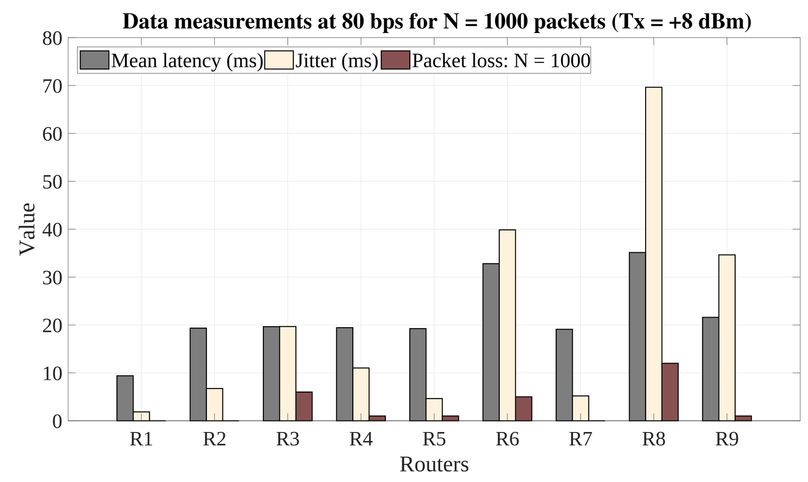

Figure 6: WSN performance at Tx = +8 dBm.

- In **Fig.5** and **Fig.6**, test results of WSN reliability and performance are presented for each node programmed at Tx = 0 dBm and Tx = +8 dBm respectively.
  - Constant package delivery error is assumed. Better performance and reliability at Tx = +8 dBm but with higher power consumption requirements.

Conclusion

- A low-power WSN was successfully implemented based on the Thread wireless technology. A simple path loss propagation model was developed to determine Line-of-Sight (LoS) RF ranges of the nRF52840 at Tx = 0 dBm. The estimated LoS distance or captured RSSI value was used to distribute router nodes (R1-R9) throughout the building area. Additional mesh links were established and greater distances covered when the nodes were set at Tx = +8 dBm. The end-device will mostly have at least one stable link provided an RSSI greater than -80 dBm to a parent router in both directions when placed at any location inside the building perimeter. However, some areas in the building do cause high decrease in signal propagation due to noise and shadowing caused by obstacles. To compensate, the WSN coverage and additional MLE redundancy may be greatly improved by incorporating additional routers in the network as depicted by R10-R22. Finally, a statistical approach was followed to represent field measurements. Results indicate reliable packet deliveries with acceptable latency delays between point to point (through mesh multi-hopping) node communications for a low data throughput application.

Future Work

- Comprehensive multipoint to multipoint node field measurements and analysis.
- Omitting end-device and incorporating multiprotocol wireless system using BLE of PCD to communicate to WSN.
- Proprietary PCD firmware development.
- nRF52840 SoC printed circuit board design and development.

References

[1] Thread-Group, 2017.
http://threadgroup.org/ThreadSpec.

[2] T. Rappaport.
Wireless communications principles and practice.
Prentice Hall, New York, 1 edition, 2002.

Acknowledgments

- This project is an initiative from the High-throughput Electronics Laboratory.

 roger.vanrensburg@wits.ac.za