# A new Wireless Protocol for Clustered 802.15.4 Transmission Network

By

**Shankha Shubhra Das**

17MCMT28

M.Tech in Computer Science

**Venkata Rahul, Satuluri**
Founder of
ConserVision Technology
University of Hyderabad

**Prof. Rajeev Wankar**
Supervisor
School of Computer and Information Sciences
University of Hyderabad

# Outline:

- 802.15.4 (LR-WPAN)
- Problem Statement
- Approach to the Existing Problem
- Network Structure
- Packet Structure
- Waiting Line / Queuing System on the new network
- Contiki (Cooja)

# 802.15.4 (LR-WPAN):

- IEEE 802.15.4 2003 was the initial release of the IEEE 802.15.4 standard. It provided for two different PHYs - one for the lower frequency bands of 868 and 915 MHz, and the other for 2.4 GHz.

- IEEE 802.15.4 2006 release of the IEEE 802.15.4 standard provided for an increase in the data rate achievable on the lower frequency bands. This release of the standard updated the PHY for 868 and 915 MHz. It also defined four new modulation schemes that could be used - three for the lower frequency bands, and one for 2.4 GHz.

- IEEE 802.15.4aThis version of the IEEE 802.15.4 standard defined two new PHYs. One used UWB technology and the other provided for using chirp spread spectrum at 2.4 GHz.The UWB PHY is allocated frequencies in three ranges: below 1 GHz, between 3 and 5 GHz, and between 6 and 10 GHz.

---


* http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf
* https://en.wikipedia.org/wiki/IEEE_802.15.4/

# 802.15.4 (LR-WPAN):

- In April, 2009 IEEE 802.15.4c and IEEE 802.15.4d were released expanding the available PHYs with several additional PHYs: one for 780 MHz band using O-QPSK or MPSK, another for 950 MHz using GFSK or BPSK.

- IEEE 802.15.4e was chartered to define a MAC amendment to the existing standard 802.15.4 – 2006 which adopts channel hopping strategy to improve support for the industrial markets, increases robustness against external interference.

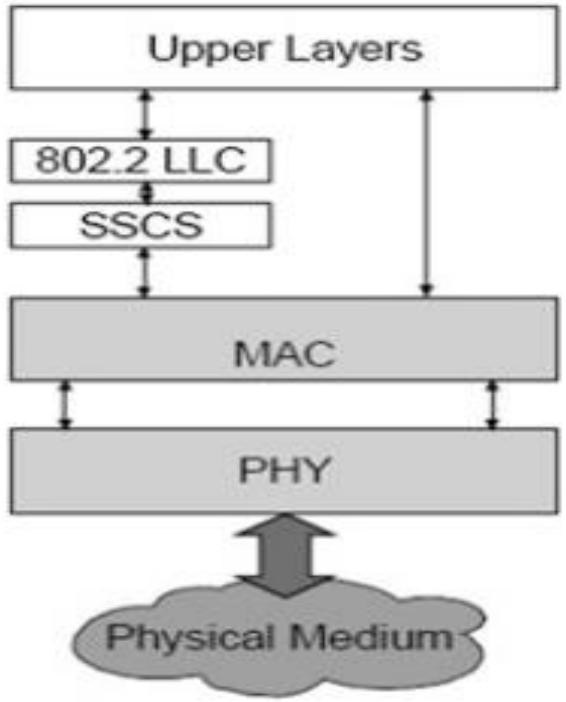


Figure: Device architecture defined in IEEE 802.15.4 (IEEE 2003)


* http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf
* https://en.wikipedia.org/wiki/IEEE_802.15.4/
* Yang, Shuang-Hua, "Wireless Sensor Networks: Principles, Design and Applications," *Principle of Wireless Sensor Networks, Chapter 2*

# 802.15.4 (LR-WPAN):

- The IEEE devised a WPAN standard based on a new set of criteria:

  - ✓ Very low complexity
  - ✓ Ultra-low power consumption
  - ✓ Low data rate
  - ✓ Relatively short radio communication range
  - ✓ Use of unlicensed radio bands
  - ✓ Easy installation
  - ✓ Low cost
  - ✓ The motivation for strict power requirement is to enable the use of battery-powered network devices that are completely free of cabling (no network or power cables) and no underlying infrastructure.

---


* http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf
* https://en.wikipedia.org/wiki/IEEE_802.15.4/
* Yang, Shuang-Hua, "Wireless Sensor Networks: Principles, Design and Applications," *Principle of Wireless Sensor Networks, Chapter 2*

# 802.15.4 (LR-WPAN):

- General characteristics:
  - Low data rate: less than 250 kbps
  - Personal operating space: 25 - 30m
  - 2 device types in LR-WPAN
    - ✓ FFD (full-function device), PAN coordinator, coordinator, device.
    - ✓ RFD (reduced-function device), can talk only with a FFD.
  - Network topologies:
    - ✓ Star topology.
    - ✓ Peer-to-peer topology.
- IEEE 802.15.4 was designed to operate in unlicensed radio frequency bands. The unlicensed RF bands are not the same in all territories of the world, but IEEE 802.15.4 employs three possible bands, at least one of this should be available in a given territory. The three bands are centered on the following frequencies: 868, 920-928 and 2400 MHz.


* http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf
* https://en.wikipedia.org/wiki/IEEE_802.15.4/
* Yang, Shuang-Hua, "Wireless Sensor Networks: Principles, Design and Applications," *Principle of Wireless Sensor Networks, Chapter 2*

# Problem Statement:

- Applications of low energy devices are increasing prominently in a variety of areas like smart energy, smart home etc.
- However as the network topology in these applications becomes more complicated, the devices will encounter bottlenecks of speed, concurrency and propagation time.
- The failure rate of transmission might also increase due to the increased collision.
- Sensor battery life is also drastically reduced due to a higher number of attempts by each sensor for successful transmission.
- The presence of Low-Rate Wireless Personal Area Network (LR-WPAN) is does threatened.

- So to overcome this crucial problem a new network structure is proposed to enrich the sensor battery life of 802.15.4 devices.

# Approach & Methods:

- **Protocol analysis:** Compare 802.11 vs. 802.15.4. Understand Low energy requirements
- **Collision Detection/Avoidance:** MAC (CSMA/CA*), existing metrics to compare.
- **H/W or S/W Simulation:** H/W feasibility. Modify Cooja source.
- **RTOS:** Contiki/RIOT

* MAC(CSMA/CA): medium access control (Carrier Sense Multiple Access / Collision Avoidance)
* H/W: Hardware, * S/W: Software, * RTOS: Real Time Operating System

# Network Structure:

- According to the IEEE 802.15.4 standard only one Personal Area Network (PAN) coordinator exist in the clustered network area, which becomes from a Full Function Device (FFD) in the network. Then Reduced Function Device (RFD) will be able to send the sensor readings regularly to the PAN coordinators through its parent FFD.

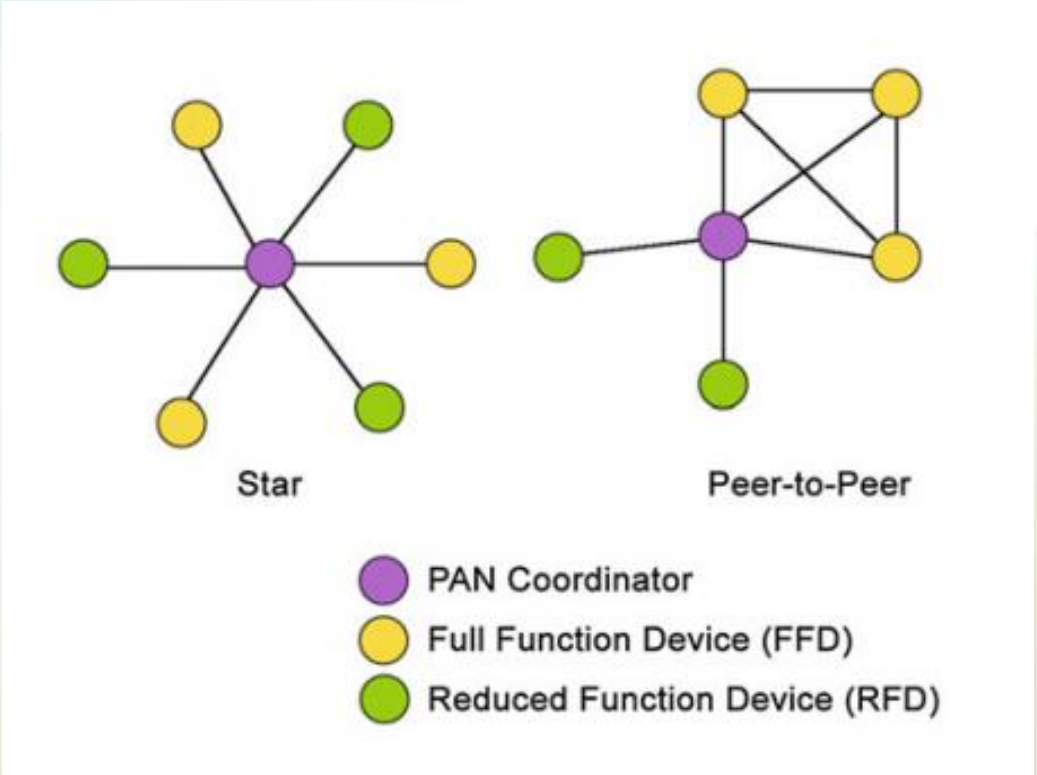


Fig: IEEE 802.15.4 topologies



* Yang, Shuang-Hua, "Wireless Sensor Networks: Principles, Design and Applications," *Principle of Wireless Sensor Networks, Chapter 2*
* http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf

# Network Structure:

- We propose multiple Personal Area Network (PAN) coordinators using Full Function Device (FFD). Then in the network, Reduced Function Device (RFD) will be able to send the sensor readings regularly to one of the chosen PAN coordinators. With this proposed approach RFD's don't have to wait long to transmit the information to the coordinators and battery life will be saved.

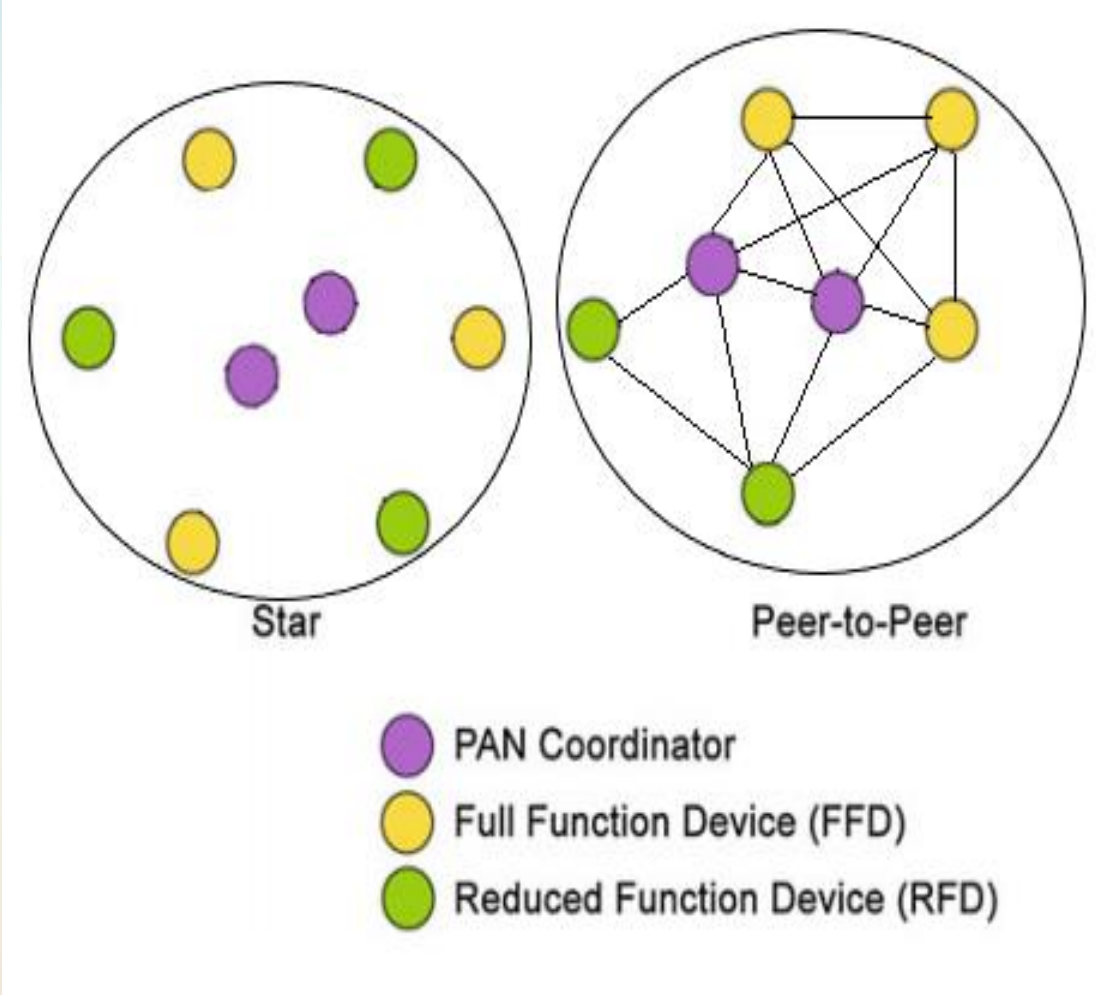


Fig: Proposed 802.15.4 topologies

# Methods:

- This dissertation deals with the 802.15.4 protocol for star topology.

- Usually, in a 802.15.4 star network, the Full Function Device (FFD) is very busy and the Reduced Function Device (RFD) nodes observe the Carrier Sense Multiple Access with collision avoidance (CSMA/CA or CSMA-CA) paths and avoid the collisions and increase the percentage of success or transmission of packets.

  - ✓ Before transmitting any packet through the channel Clear Channel Assessment (CCA) is performed to sense the carrier is available or not? If it's available the transmission takes place.
  - ✓ In the packet structure, Media Access Control (MAC) layer frame we are going to modify the structure by adding extra information of Destination Address to transmit data packet to the alternate address while other one is busy.

# Packet Structure:

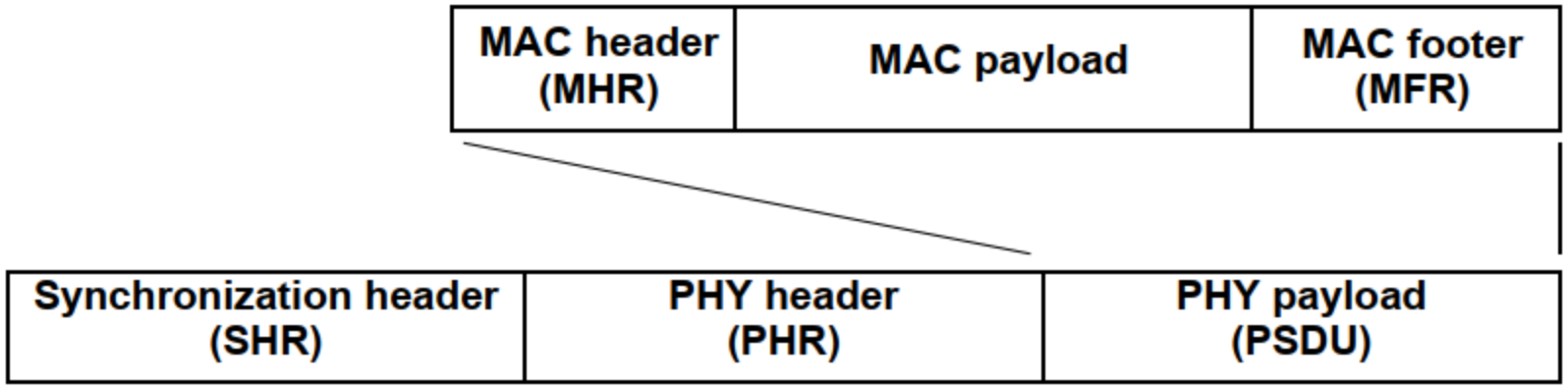


Figure: Schematic view of the PPDU

- The frame structures have been designed to keep the complexity to a minimum while at the same time making them sufficiently robust for transmission on a noisy channel. Each successive protocol layer adds to the structure with layer-specific headers and footers. This standard defines four Media access control (MAC) frame structures:
  - ✓ A beacon frame, used by a coordinator to transmit beacons.
  - ✓ A data frame, used for all transfers of data.
  - ✓ An acknowledgment frame, used for confirming successful frame reception.
  - ✓ A MAC command frame, used for handling all MAC peer entity control transfers.

* http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf

# Packet Structure:

| Preamble | Delimiter | Header | Physical Data Service Unit (PSDU) |
|---|---|---|---|
| 4 bytes | 1 byte | 1 byte | <= 127 bytes |

Fig. 2. Physical layer packet structure

| Frame control | Sequence number | Dst Address | Src Address | Payload | Frame check sequence |
|---|---|---|---|---|---|
| 2 bytes | 1 byte | 0-20 bytes | | Variable | 2 bytes |

Fig. 3. MAC layer frame structure

- In the frame structure, in place of only one 'source address' we are modifying the frame structure with multiple source address by using one byte from the existing 20 bytes.
- From the MAC layer frame structure, after using fixed bytes for payload remaining bytes can be used for multiple address in the frame structure.

* https://wiki.aalto.fi/download/attachments/59704179/devadiga-802-15-4-and-the-iot.pdf?version=1

# Packet Structure:

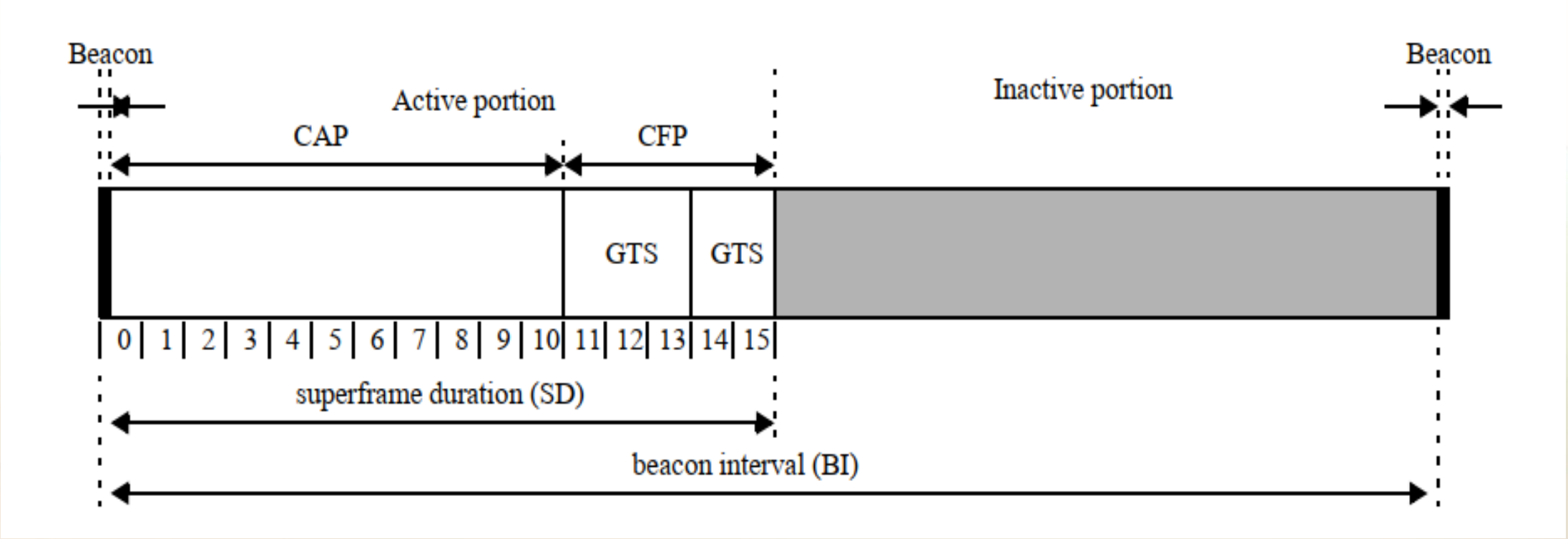


Figure: The Superframe Structure

# Waiting Line / Queuing System:

$\lambda$ = mean arrival rate of customers (average number of customers arriving per unit of time)

$\mu$ = mean service rate (average number of customers that can be served per unit of time)

$p = \frac{\lambda}{\mu}$ = the average utilization of the system

$L = \frac{\lambda}{\mu - \lambda}$ = the average number of customers in the service system

$L_Q = pL =$ the average number of customers waiting in line

$W = \frac{1}{\mu - \lambda} =$ the average time spent waiting in the system, including service

$W_Q = pW =$ the average time spent waiting in line

$P_n = (1 - p)p^n$ = the probability that $n$ customers are in the service system at a given time

* Randolph Nelson, "Probability, Stochastic Processes, and Queueing Theory" Chapter 18

# Network Measurement:

- For the new proposed protocol, the 802.15.4 protocol needs to be tweaked and the following metrics need to be compared between both the approaches.
- **Packet Reception Rate(PRR):** the percentage of received frames within a particular observation interval.
- **Packet Loss Rate(PLR):** the percentage of lost frames within a particular observation interval.
- **Packet Collision Rate(PCR):** is the number of data packet collisions occurring in a network over a specified period of time.
- **Throughput:** the observed rate at which data is sent through a channel.
- **Density:** is the number of nodes that were active during the experiment observation interval.

* PatrickR Casey, Kemal Tepe, Narayan Kar – *"Design and Implementation of a Testbed for IEEE 802.15.4 (Zigbee) Performance Measurements" 2010.*

# Protocol Metrics:

- The protocol metrics generated with the previously mentioned network measurement parameters.
- The metrics are used to compare resultant values of the network for both cases with single and more than one PAN coordinator in the network.
- For the performance of the IEEE 802.15.4 network following dataset was tested. Dataset details are following:
- **Dataset used:** 802_15_4_MAC_perf
- The 802_15_4_MAC_perf datasets is a repository that stores measurements collected from the wilab2 testbed facility in Ghent about the MAC layer performance in IEEE 802.15.4 networks. The data is collected for the research on modeling the MAC-level performance in wireless sensor networks.

* https://github.com/merimak/802_15_4MACperf_datasets
* https://ewine-project.eu/grand-challenge

# Protocol Metrics:

- **Experimental setup:** To understand the MAC-level packet delivery performance several experiments in the wilab2 testbed have been set up.
  - **Sensor Node:** RM090
  - **No. of Sensor Nodes:** 28
  - **Network Protocol:** IEEE 802.15.4
  - **Media Access Control (MAC):** CSMA/CA (Carrier Sense Multiple Access with collision avoidance.)
  - **Message Rate:** 100 B
  - **Transmission Power:** 5 dBm
  - **Traffic Load:** 1pckt/2s, 1pckt/s, 2pckts/s, 4pckts/s, 8pckts/s, 16pckts/s and 64pckts/s
  - **Channel Occupancy Ratio:** 20% (transmitting a modulated carrier for 2ms, followed by a 8ms idle period.)

* https://github.com/merimak/802_15_4MACperf_datasets
* https://ewine-project.eu/grand-challenge

# Protocol Metrics:

| NumOfReceived | PRR | packetLoss | PLR | throughput | IPI | Density | COR |
|---|---|---|---|---|---|---|---|
| 507 | 0.838017 | 98 | 0.161983 | 13520 | 32 | 5 | 10 |
| 411 | 0.665049 | 207 | 0.334951 | 11028.93 | 32 | 5 | 10 |
| 296 | 0.596774 | 200 | 0.403226 | 7895.389 | 32 | 5 | 10 |
| 248 | 0.517745 | 231 | 0.482255 | 6665.403 | 32 | 5 | 10 |
| 284 | 0.581967 | 204 | 0.418033 | 7577.28 | 32 | 5 | 10 |
| 269 | 0.660934 | 138 | 0.339066 | 7182.685 | 32 | 5 | 10 |
| 228 | 0.794425 | 59 | 0.205575 | 6084.753 | 32 | 5 | 10 |
| 221 | 0.917012 | 20 | 0.082988 | 5894.881 | 32 | 5 | 10 |
| 191 | 0.776423 | 55 | 0.223577 | 5094.66 | 32 | 5 | 10 |
| 152 | 0.644068 | 84 | 0.355932 | 4119.856 | 32 | 5 | 10 |
| 191 | 0.74902 | 64 | 0.25098 | 5099.973 | 32 | 5 | 10 |

* https://github.com/merimak/802_15_4MACperf_datasets
* https://ewine-project.eu/grand-challenge

# Contiki:

- Contiki is an open source, highly portable, multi-tasking operating system for memory efficient networked embedded systems and wireless sensor networks.
- Features of Contiki:
  - ✓ TCP/IP communication with uIP stack
  - ✓ Loadable modules
  - ✓ Event-driven kernel
  - ✓ Protothreads
  - ✓ Protocol-independent radio network with the Rime stack
  - ✓ Cross-layer network simulation with Cooja

# Contiki:

- Operating System
  - ✓ memory-efficient: 2 kB RAM, 40 kB ROM typically
  - ✓ provides IP support (its uIPv6 stack is IPv6 Ready)
  - ✓ supports Protothreads
  - ✓ runs on many embedded platforms
  - ✓ comes with advanced simulators
- Written in C, under BSD License
- Memory footprint
  - ✓ RAM: 2 KB
  - ✓ ROM: 30 KB
- Microcontroller Architecture Support: AVR, MSP430, ARM7, ARM Cortex-M, PIC32, x86, 6502
- Network Protocol: 802.15.4,BLE,RPL,Coap,MQTT
- Cooja: Cooja is the Contiki network simulator. Cooja allows large and small networks of Contiki motes to be simulated.

# Reference:


- IEEE 802.15.4 http://ecee.colorado.edu/~liue/teaching/comm_standards/2015S_zigbee/802.15.4-2011.pdf
- Yang, Shuang-Hua, "Wireless Sensor Networks: Principles, Design and Applications", Principle of Wireless Sensor Networks, Chapter 2
- William Stallings, "Data and Computer Communication", Tenth Edition
- PaoloBaronti, PrashantPillai, Vince W.C. Chook, Stefano Chessa, Alberto GottabY, Y. Fun Hu, "Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards"
- Randolph Nelson, "Probability, Stochastic Processes, and Queueing Theory"
- https://www.researchgate.net/
- http://www.prismmodelchecker.org/casestudies/zigbee.php#protocol/
- https://github.com/merimak/802_15_4MACperf_datasets/
- https://ewine-project.eu/grand-challenge/
- http://www.ti.com/
- http://www.contiki-os.org/start.html/
- https://riot-os.org/

# Thank You