Reliability and Energy Efficiency Enhancement in Wireless Body Area Networks (WBANs) for E-Health

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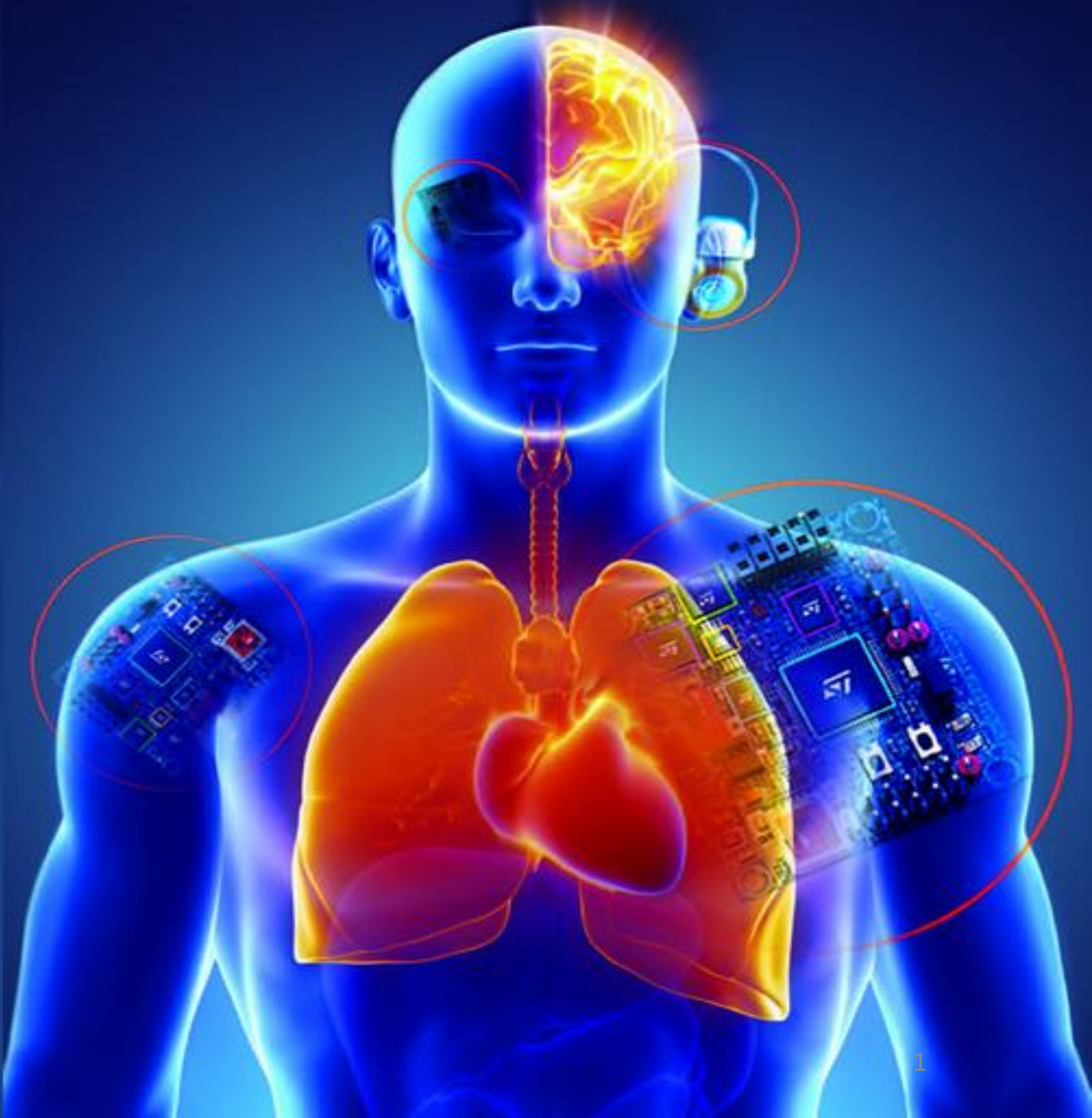


Overview

This work proposes:

- Adaptive channel access mechanism for WBAN.
- The protocol is TDMA based.
- Harnesses the vulnerability of WBAN channel in re-allocating time slot dynamically, while saving energy.
- The protocol is an enhancement to the IEEE 802.15.4 beacon enabled MAC.

The aim of the this work:

- To improve reliability and energy efficiency of WBAN for E-Health.

What is WBAN?

EEG
EMG
ECG
Blood Pressure
Temperature
Motion
Smartphone
Internet
Emergency
Medical Database
Home Computer
Physician

WBAN Challenges: Reliability

- **Topology:**

  Dynamic, frequent, uncontrolled

- **Signal Energy Absorption:**

  Tissue Heating

WBAN Challenges: Reliability

Channel attenuation

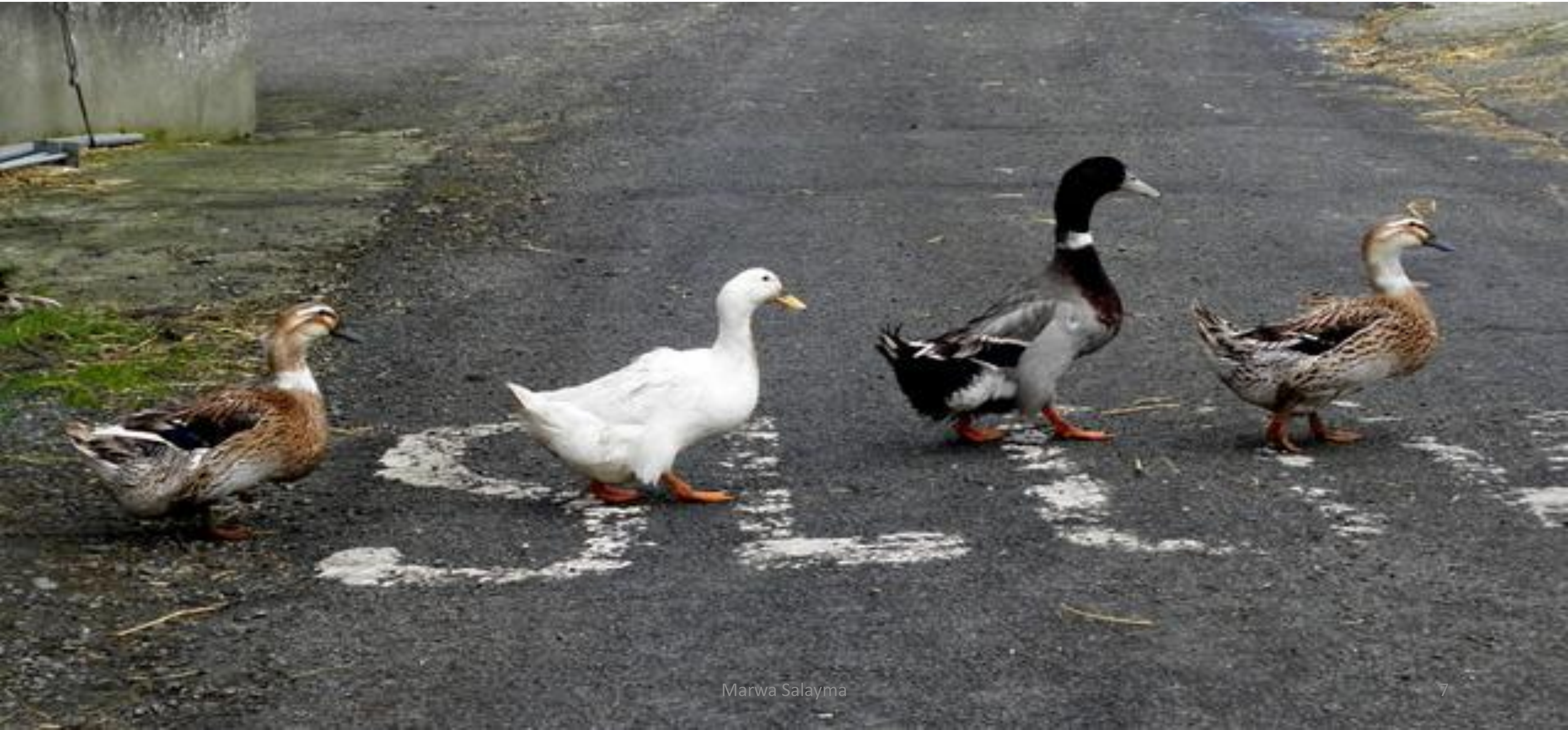
&

Deep fading **(at least 10 ms)**

WBAN Challenges

Power Consumption

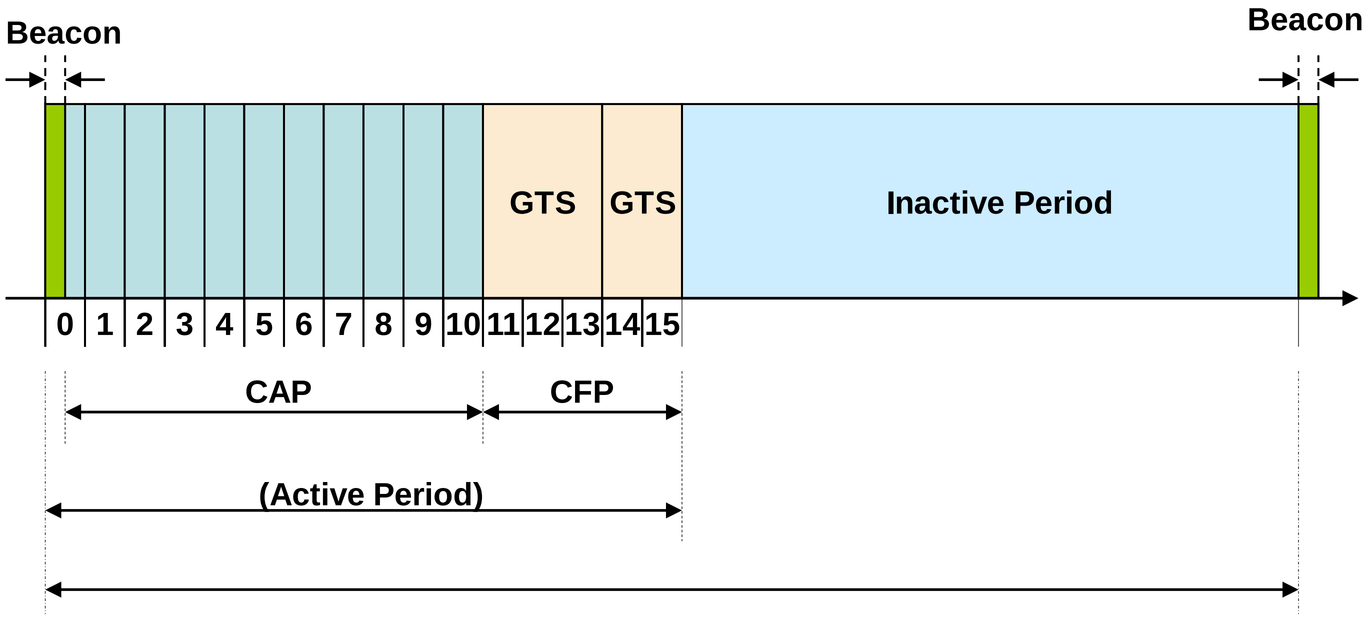
Medium Access Control (MAC)



TDMA is the best choice for WBAN MAC

- ✓ TDMA is **reliable**.
- ✓ TDMA is **energy efficient**.
- ✓ TDMA helps **predict WBAN channel status**.

IEEE 802.15.4 MAC Superframe (Beacon Enabled)



CAP: Contention Access Period

CFP: Contention Free Period

GTS: Guaranteed Time Slot

Problems:

✓IEEE 802.15.4 provides **static** GTS(s) allocations.

✓ IEEE 802.15.4 provides **static** inactive period.

Solution 1: Adaptive Sleep IEEE 802.15.4 MAC

- Instead of allowing nodes to sleep blindly at the end of the superframe, nodes themselves choose to sleep adaptively according to their link status.

- Whenever a node detects fading in its link with the PANc, the node switches off its transceiver directly.

- The node will continue sleeping until the current BI finishes, and wakes up to receive the next beacon frame as usual.

- In this way, nodes sleeps dynamically according to their link status with the PANc.

- We call this technique **Adaptive Sleep IEEE 802.15.4 MAC.**

- Adaptive Sleep IEEE 802.15.4 MAC saves energy, and avoid data packet loss.

Performance Evaluation

We examined the feasibility of Adaptive Sleep IEEE 802.15.4 MAC in:

- Improving reliability in terms of packets loss rate and latency.
- Increasing energy efficiency (decreasing energy consumption).

We adopted two scenarios:

MAC/Scenarios	Legacy IEEE 802.15.4 MAC	Adaptive Sleep IEEE 802.15.4 MAC
Scenario 1	25% duty cycle	50% cycle
Scenario 2	50% duty cycle	50% cycle

Simulation Setup

Parameter		Value
Simulator Physical and MAC model		Castalia 3.3 IEEE 802.15.4
Simulation time (s)		500
Number of nodes		6 (1PANc and 5 nodes)
Tx power (dBm)		-15
GTS(s)		15 each node assigned 3 GTS
Buffer size (byte)		32
Traffic model		CBR (normal traffic)
Traffic rate (p/s)	Low	1, 5
	Moderate	10, 20
	High	50
	Very high	100
Payload size (byte)		105
BO value		6
SO Values		4, 5

Results

Performance	**Scenario 1** (25% duty cycle Legacy IEEE 802.15.4 vs. 50% duty cycle Adaptive Sleep)	**Scenario 2** (50% duty cycle Legacy IEEE 802.15.4 vs. 50% duty cycle Adaptive Sleep)
Decreases packets loss	Adaptive Sleep IEEE 802.15.4 (at all traffic rates)	Adaptive Sleep IEEE 802.15.4 (at low, moderate and high traffic)
Decreases latency	Adaptive Sleep IEEE 802.15.4 (at all traffic rates)	Legacy IEEE 802.15.4
Decreases energy consumption	Legacy IEEE 802.15.4	Adaptive Sleep IEEE 802.15.4

* Extra sleep periods causes buffer overflow at high traffic rates, and increases latency, whilst decreasing energy consumption.

Solution 2: Dynamic GTS IEEE 802.15.4 MAC

- **To decrease latency:**

- Allow nodes to sleep whenever they detect fading in the channel, and make it up for the nodes later by giving them extra slots.

- Time slot allocation is going to be dynamic according to nodes' needs.

- **How many extra slots?**

1. Depend on the total number of the superframe slots.

2. Number of links faced fading in the previous round.

3. Minimum number of slots each node should acquire.

Example

- IEEE 802.15.4 provides 16 time slots superframe.
- We have 5 nodes, then each node acquirers 3 GTS(s) once the network is established.
- According to the slot size and network configurations, 3 links at maximum faced fading during any round.
- The minimum number of slots each node should acquire is 2.
- During the network operations, extra slots will be granted to nodes according to the following pattern:
- If one link faced fading, the node of that link will be re-assigned 7 slots , while the remaining nodes will be allocated 2.
- If two links faced fading: one node (of that link) will be assigned 5 slots (the node which slept first) and one 4 slots, and rest of nodes 2 slots.
- If three links faced fading: two will be assigned 4 slots and one 3 slots while the rest of nodes 2 slots.

Performance Evaluation

The feasibility of enhancing Adaptive Sleep IEEE 802.15.4 MAC performance, by adopting Dynamic GTS IEEE 802.15.4 MAC is examined in terms of:

- Improving reliability in terms of packets loss and latency.
- Increasing energy efficiency.

We adopted two scenarios:

MAC/Scenarios	Legacy IEEE 802.15.4	Adaptive Sleep IEEE 802.15.4	Dynamic GTS IEEE 802.15.4
Scenario 1	25% duty cycle	50% duty cycle	50% duty cycle
Scenario 2	50% duty cycle	50% duty cycle	50% duty cycle

Results

Performance	**Scenario 1** (25% duty cycle Legacy IEEE 802.15.4 vs. 50% duty cycle Dynamic GTS)	**Scenario 2** (50% duty cycle Legacy IEEE 802.15.4 vs. 50% duty cycle Dynamic GTS)
Decreases latency	Dynamic GTS IEEE 802.15.4	Dynamic GTS IEEE 802.15.4
Decreases energy consumption	Legacy IEEE 802.15.4 (but Dynamic GTS outperforms Adaptive Sleep)	Dynamic GTS IEEE 802.15.4

Conclusions and Future work

- WBAN reliability and energy efficiency can be improved by adopting a TDMA based channel access mechanisms that consider channel status.

- WBAN channel deep fade is used as criterion to dynamically allocate slots to nodes.

- The two proposed techniques are generic, as they do not require amendments to the legacy IEEE 802.15.4 specifications.

- **As a future work**, allocating time slots will be also based on the actual medical status of the nodes, which indicates whether the node in normal or emergency situation.

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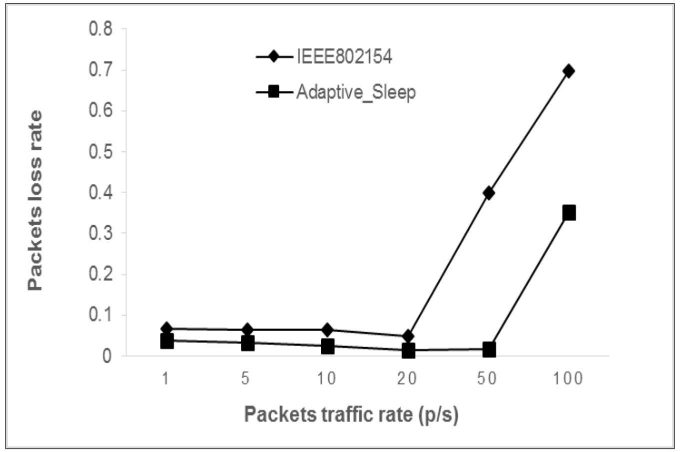
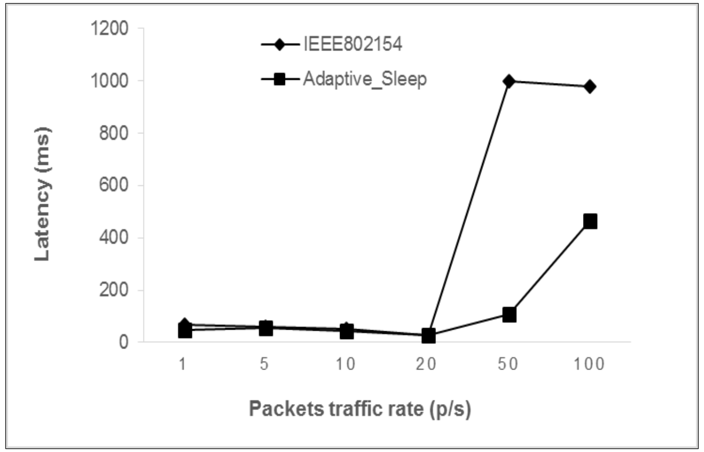
IEEE 802.15.4 VS. Adaptive Sleep IEEE 82.15.4

Scenario1: 25% duty cycle IEEE 802.15.4 VS. 50% duty cycle Adaptive Sleep IEEE 82.15.4

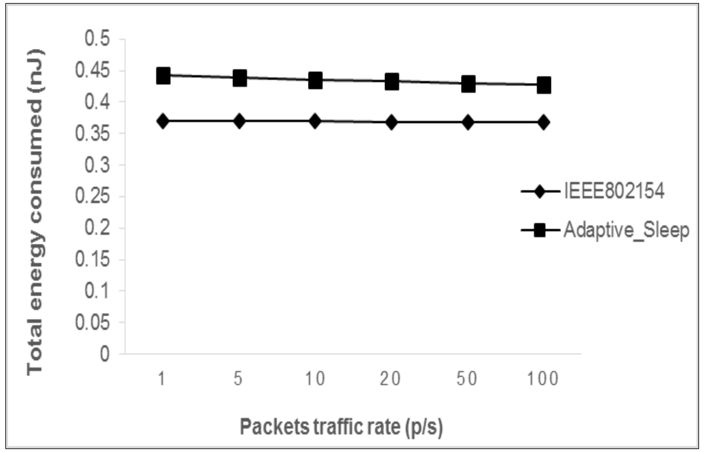
Packets loss rate



Latency (ms)



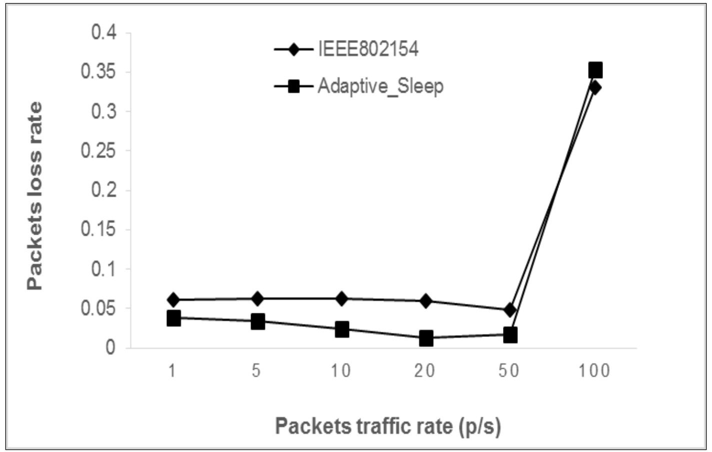
Energy Consumption (nJ)



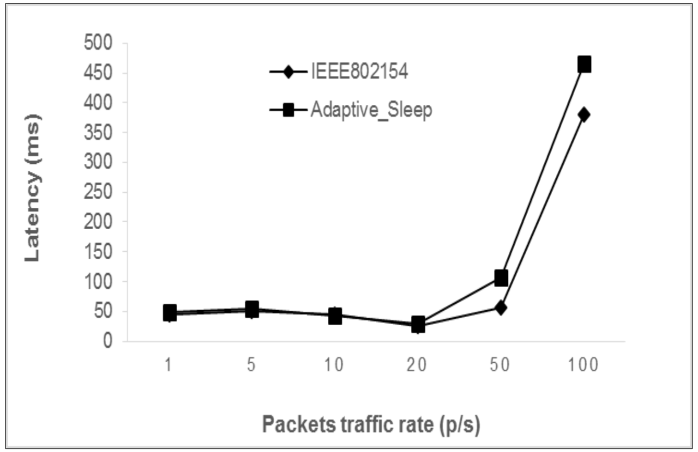
IEEE 802.15.4 VS. Adaptive Sleep IEEE 82.15.4

Scenario2: 50% duty cycle IEEE 802.15.4 VS. 50% duty cycle Adaptive Sleep IEEE 82.15.4

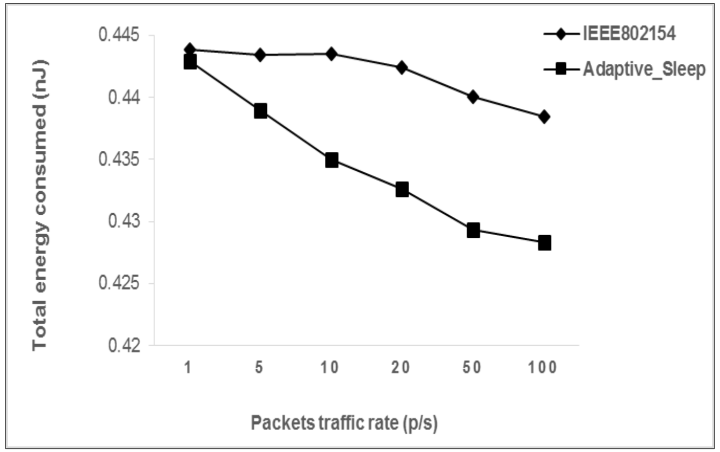
Packets loss rate



Latency (ms)



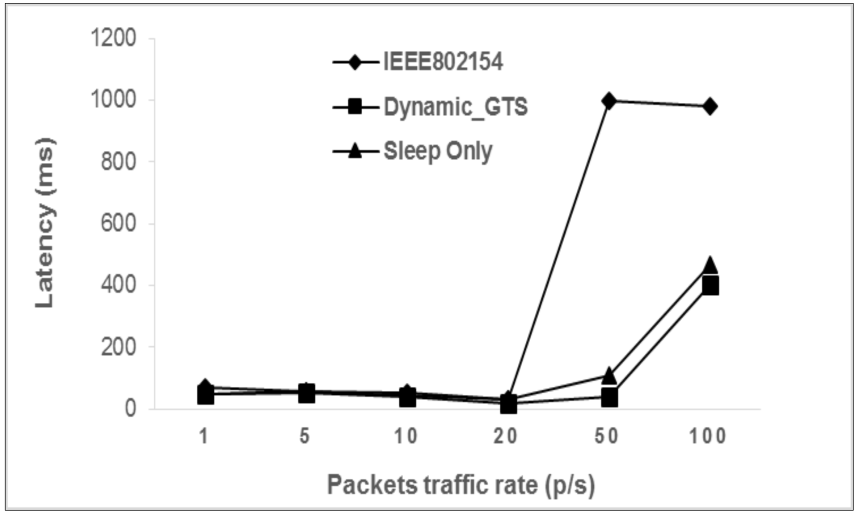
Energy Consumption (nJ)



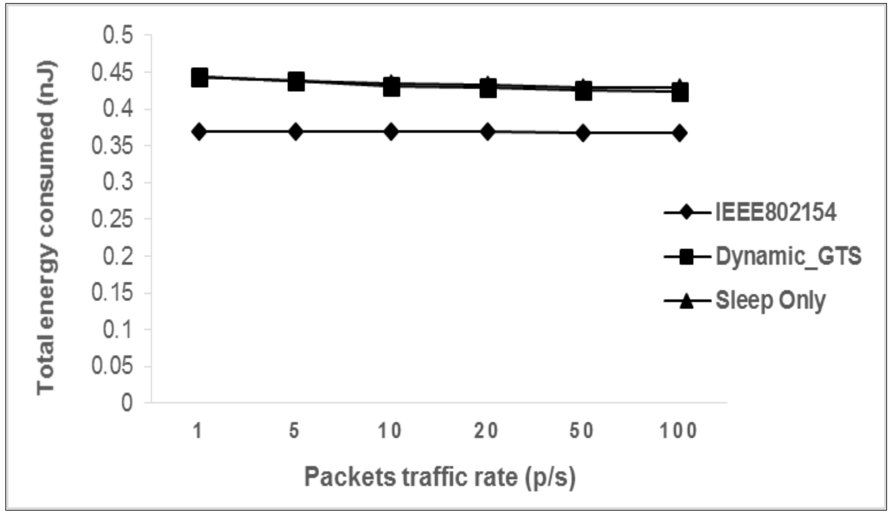
IEEE 802.15.4 VS. Dynamic GTS IEEE 82.15.4

Scenario1: 25% duty cycle IEEE 802.15.4 VS. 50% duty cycle Dynamic GTS IEEE 82.15.4

Latency (ms)



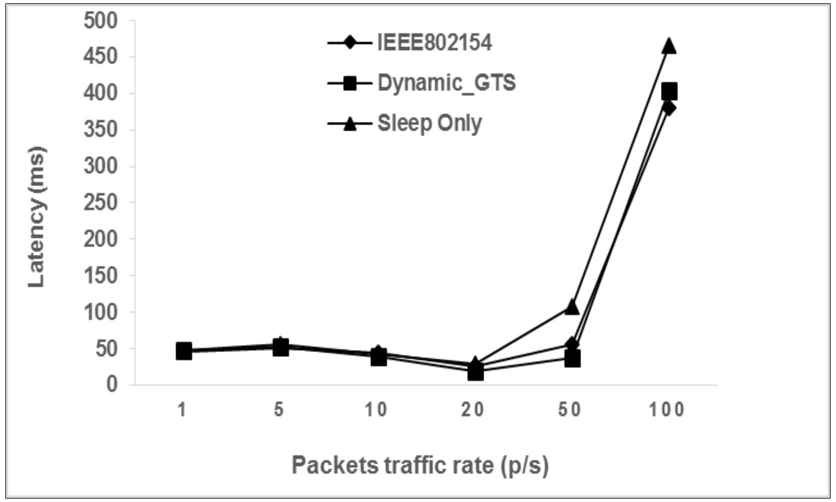
Energy Consumption (nJ)



IEEE 802.15.4 VS. Dynamic GTS IEEE 82.15.4

Scenario2: 50% duty cycle IEEE 802.15.4 VS. 50% duty cycle Dynamic GTS IEEE 82.15.4

Latency (ms)



Energy Consumption (nJ)