Project: IEEE P802.15 Working Group for Wireless Specialty Networks

Submission Title: Low Complexity Adaptive Schemes for Energy Detection Threshold in the IEEE802.15.6 CSMA/CA

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Re: In response to call for technical contributions to the TG6ma MAC

Abstract: This document contains several low complexity adaptive algorithm for the energy detection threshold in IEEE802.15.6. It is intended to enhance the MAC performance with Inter-BAN interference.

Purpose: Adaptive Schemes for Energy Detection Threshold in the IEEE802.15.6ma CSMA/CA

Outline

- Background: Body Area Networks & CSMA/CA Transmission Protocol in IEEE802.15.6
- Simulation Platform
- Objective of this Study & Previous Results
- Proposed Algorithms
- Simulation Scenarios
- Results
- Conclusions

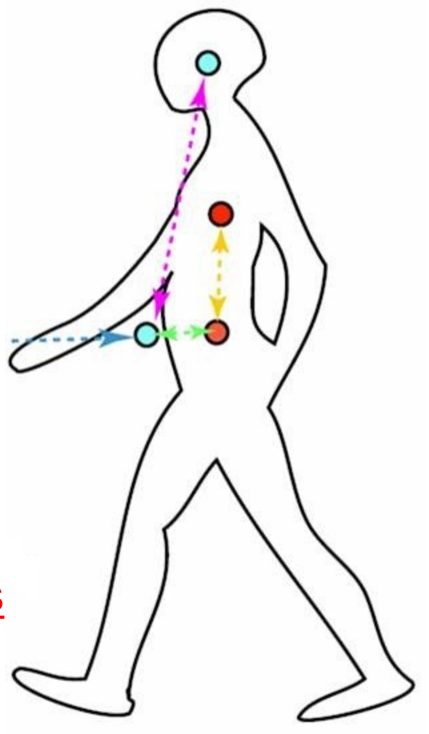
IEEE802.15.6: Body Area Networks

- A Body Area Network (BAN) is a radio communication protocol for short range, low power and highly reliable wireless communication for use in close proximity to, or inside, a human body

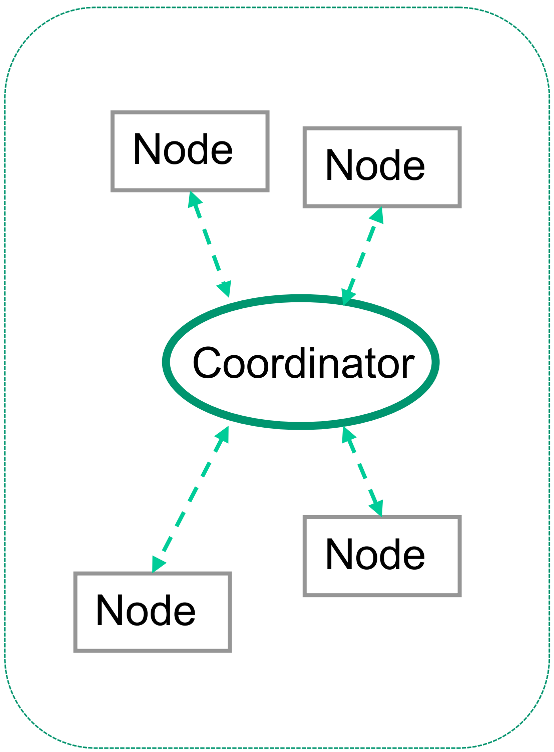
- Interference from coexisting wireless networks or other nearby BANs could create problems on the reliability of a BAN operation

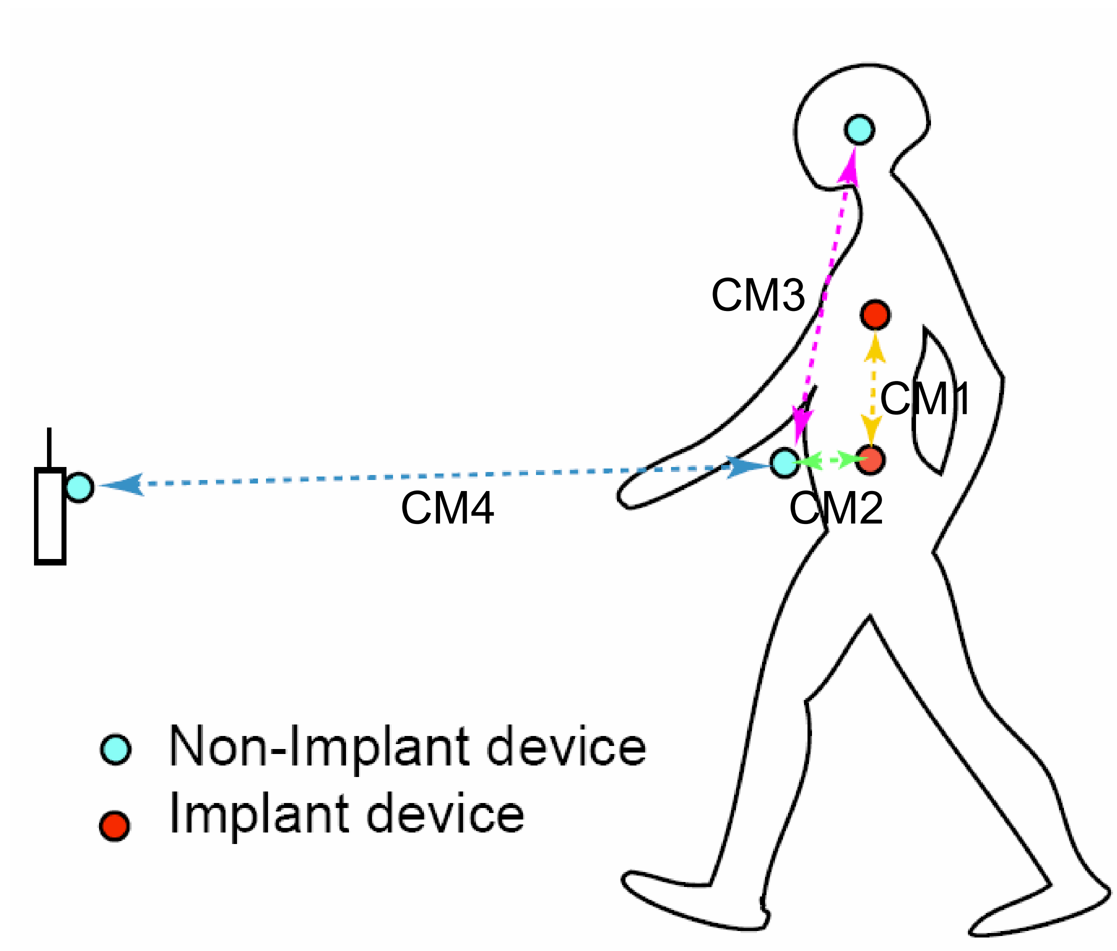
- As no coordination across multiple adjacent BANs exists, cross-interference could occur among them

- There is a need to evaluate this interference and design appropriate Mitigation techniques (e.g. for medical applications that require high reliability)



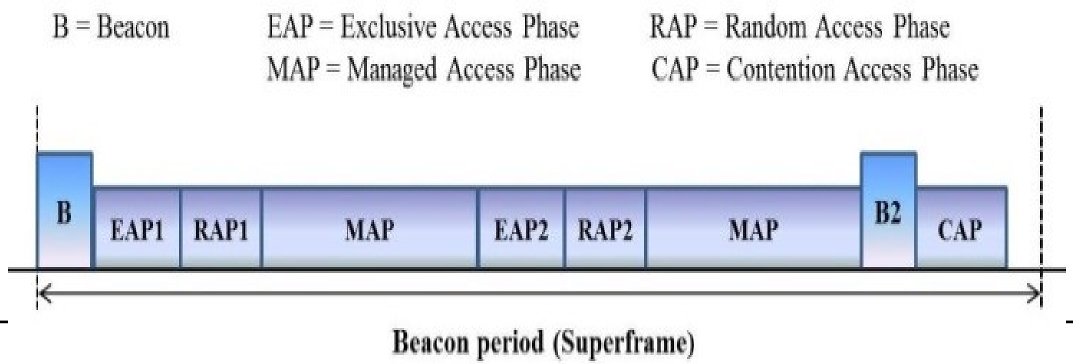
Architecture and the Operating Scenarios





CSMA/CA transmission protocol in IEEE802.15.6

- The SF structure is divided into Exclusive Access Phases (EAP1, EAP2), Random Access Phases (RAP1, RAP2), Managed Access Phases (MAP) and a Contention Access Phase (CAP).
- In EAP, RAP, CAP periods nodes in a BAN contend for resource allocation using either slotted aloha or CSMA/CA access procedure.
- A node assessment of the transmission channel (i.e. idle/free) is done according to the Clear Channel Assessment (CCA) Mode 1 described in the standard document. It involves the use of an Energy Detection (ED) threshold.



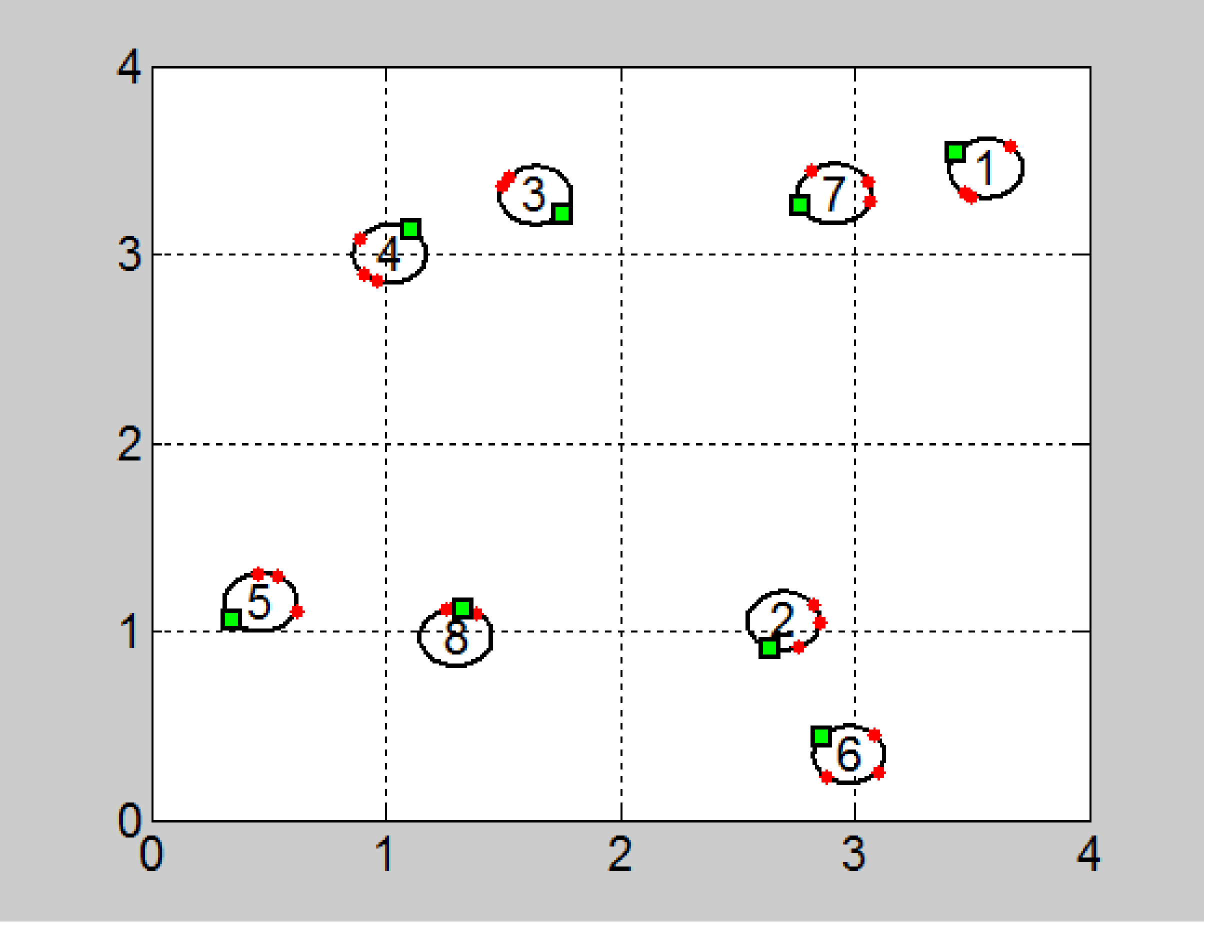
- The CSMA/CA MAC protocol as outlined in the IEEE802.15.6 BAN standard involves the use of an energy detection threshold to determine the status of the transmission channel i.e. idle versus busy.
  - The use of such static thresholds could negatively impact the performance of the system composed of multiple co-located BANs.
  - It could also lead to starvation or unfair treatment of a node that is experiencing excessive interference due to its physical location relative to all other nodes in the system.

Multi-BAN Simulation Platform to Study CSMA/CA in IEEE802.15.6

- Ultimately, a comprehensive measurement campaign is needed to evaluate cross-interference and determine its impact on the BAN link operation
- This is quite challenging, as there are many factors in the implementation that could affect the amount of cross-BAN interference
- Therefore, a simulation platform that can help to estimate or better characterize this interference could be very helpful
- As a first step, we have developed a simple MATLAB-based environment that can emulate multi-BAN scenarios with motion capability

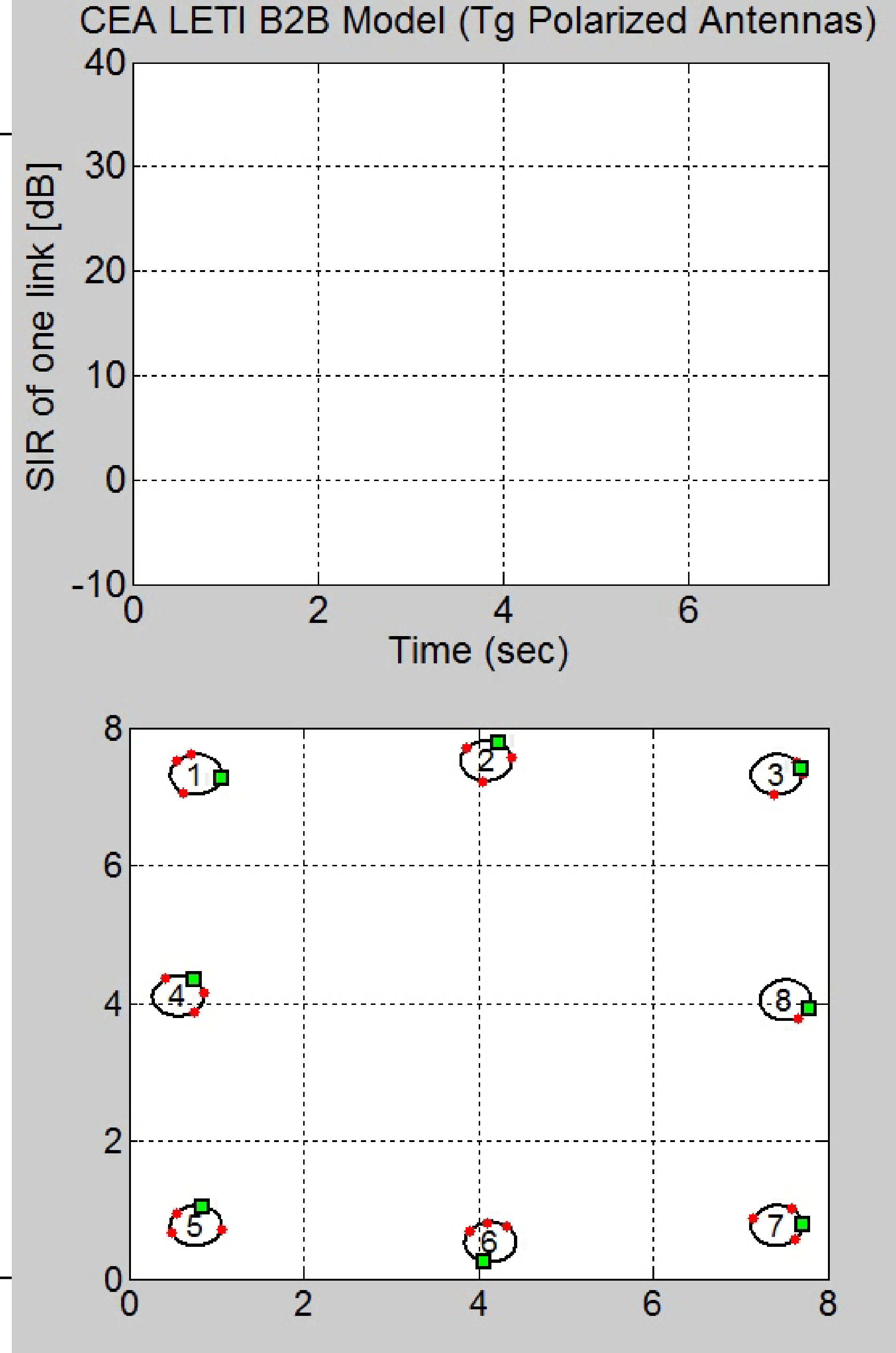
Simulation Platform

- A virtual room with variable dimensions, Variable number of BANs, Variable number of sensor Nodes
- Each BAN is capable of moving in a given direction with the desired speed
- Several statistical models representing on-body and BAN-to-BAN channels have been incorporated
- Initially we have focused on 2.4 GHz



<u>Sample Circle Scenario:</u>

A monotonically increasing Interference scenario



A Multi-BAN System

Consider a system comprised of N BANs. The experienced Signal to Interference plus Noise ratio (SINR) at the receiver node (with transmitter node $l \neq i$) of BAN $k = 1,..,N$ can be expressed by:

$$SNIR_{li}^{k} = p_l^k \xi_{li}^k / (\sigma_i^2 + I_i)$$

p_l^k : transmission power for the transmitting node $l = 1,...,M$ in BAN k

σ_i^2 : noise power at receiver i

ξ_{li}^k : Channel attenuation from a transmitting node l in BAN k to the receiver node i in BAN k

I_i : Interference at receiver i created by other BANs $j \neq k$ and eventually by sensors of the same BAN k which are concurrently transmitting

$$I_i = \sum_{j \neq k} p_m^j \xi_{mi}^j + \sum_{k,n \neq l} p_n^k \xi_{ni}^k$$

Channel Models Incorporated in the Simulation Platform

- On-Body Channel Models (IEEE802.15.6)
- NICTA Off-Body Channel Model (IEEE802.15.6)

$$P(d,\alpha,A,L) = G(d,\alpha,A,L) + F(d,\alpha,A,L)$$

d = Distance (m)
α = Orientation (°)
A = Action Type
L = Tx Location

- CEA LETI Heuristic B2B model
  - Tangentially and Normally Polarized Antennas

$$P(d,\alpha) = G(d,\alpha) + F(d)$$

Where

$$G(d,\alpha) = G(d_0,\alpha) - 10 \cdot n(\alpha) \cdot \log_{10}(d/d_0)$$

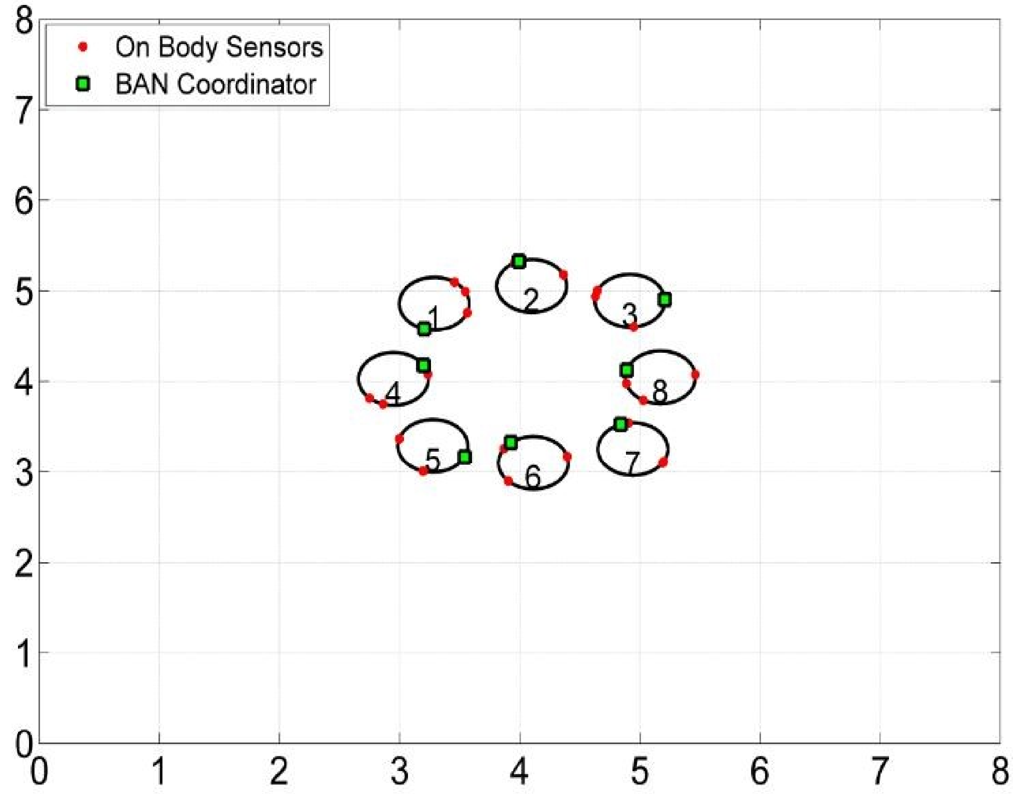
$F(d)$ modeled by a Rice Distribution

d = Distance (m)
α = Orientation (°)

d_0 = 1m
$n(\alpha)$ = PL Exponent

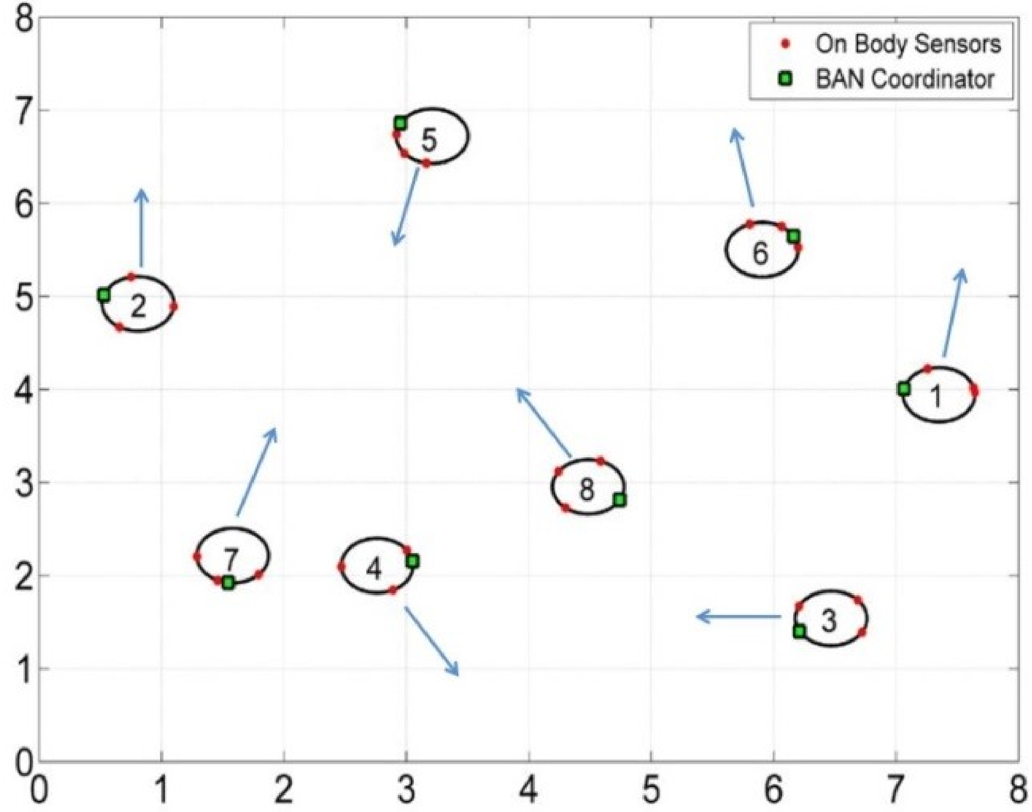
Simulation Scenario 1: Static

The first simulation scenario consist of eight BANs (each having 3 on-body sensors and one coordinator node) that are static and at a fixed distance from each other



Simulation Scenario 2: Random Movements

The second simulation scenario considers eight BANs (again with 3 on-body sensor nodes and one coordinator) moving randomly in a room with a size of 8m × 8m



Assumptions

- We have implemented a simplified version of the IEEE 802.15.6 CSMA/CA MAC protocol on this platform.
  - Only the Contention Access Phase (CAP) in the SF has been considered
- We have only used channel models associated with tangentially polarized antennas, as they result in less inter-BAN interference compared with normally polarized antennas
- The operating frequency of each BAN is considered to be 2.36 GHz (i.e. MBAN frequency band) as adopted by FCC for use in indoor environment
- All transmissions are using the same frequency channel
- There are no hidden node problem within each BAN i.e. simultaneous transmissions within the same BAN may occur only if sensor nodes set their BC to the same random value.

Assumptions (Cont')

- The packet generation rate per sensor $(i.e.\ GenRate)$ varies in the interval [0 1] and represents the probability that a sensor has a new packet arrival at the beginning of each SF.
  - The traffic model used is an i.i.d. Bernoulli with variable rates between 0 and 1 (packets per SF)

- Traffic load per BAN is defined as:

$$Traffc\ Load = GenRate\ X \frac{Packet\ Length}{SF\ Length} X\ Num\ of\ Sensors\ per\ BAN$$

- Assumed an infinite size queue (to accommodate the backlogged traffic) along with an unlimited number of retransmissions for the arrival traffic at each node of a BAN.

Evaluation Metrics

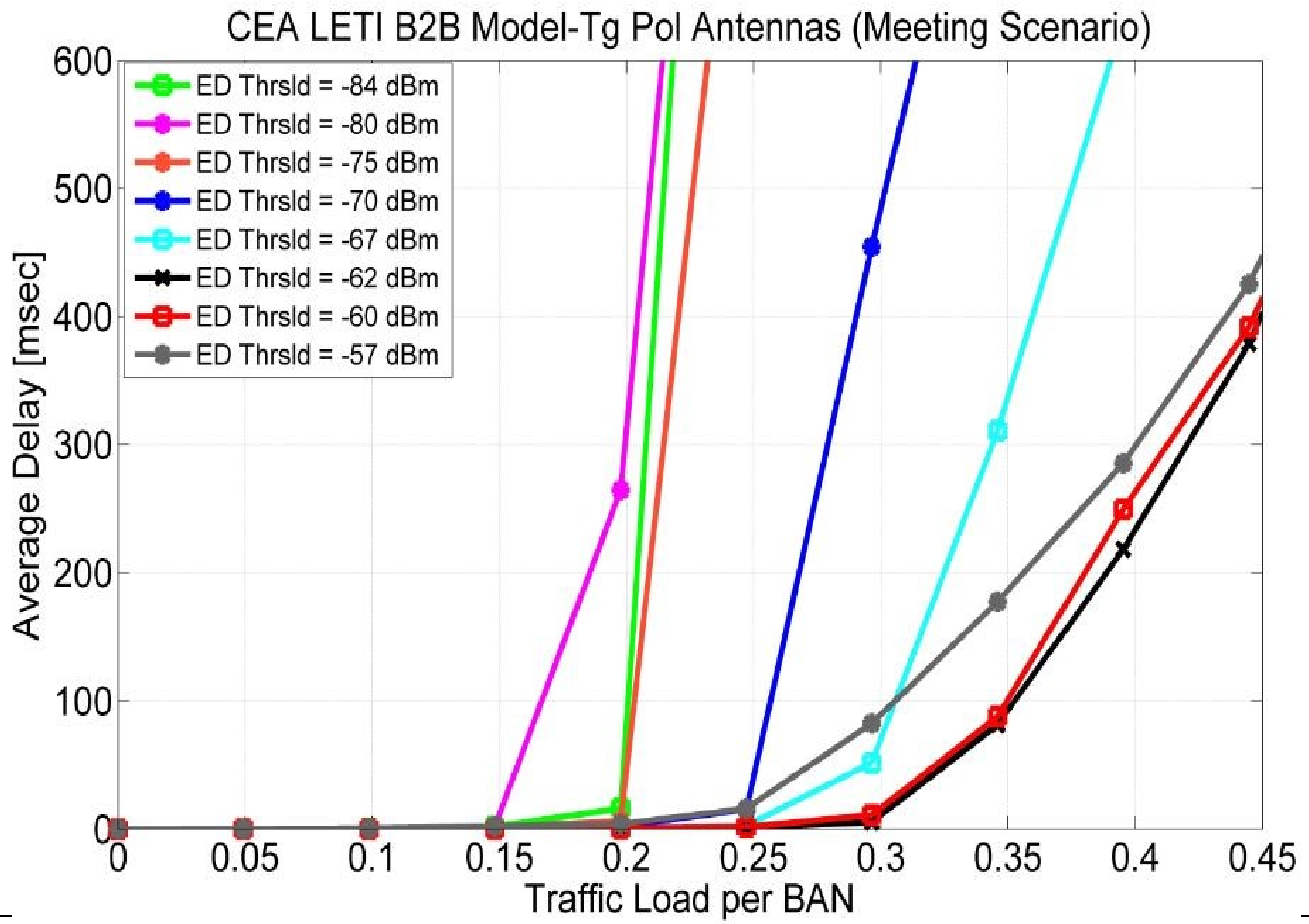
- System performance is evaluated in terms of the Average Packet Delay which is defined as the interval of time between packet generation and its correct reception at the coordinator. Using Little's theorem, average packet delay can be computed as follows:

$$Average\ Packet\ Delay = \frac{Average\ \#\ of Packets\ per\ Queue}{Packet\ Generation\ Rate}$$

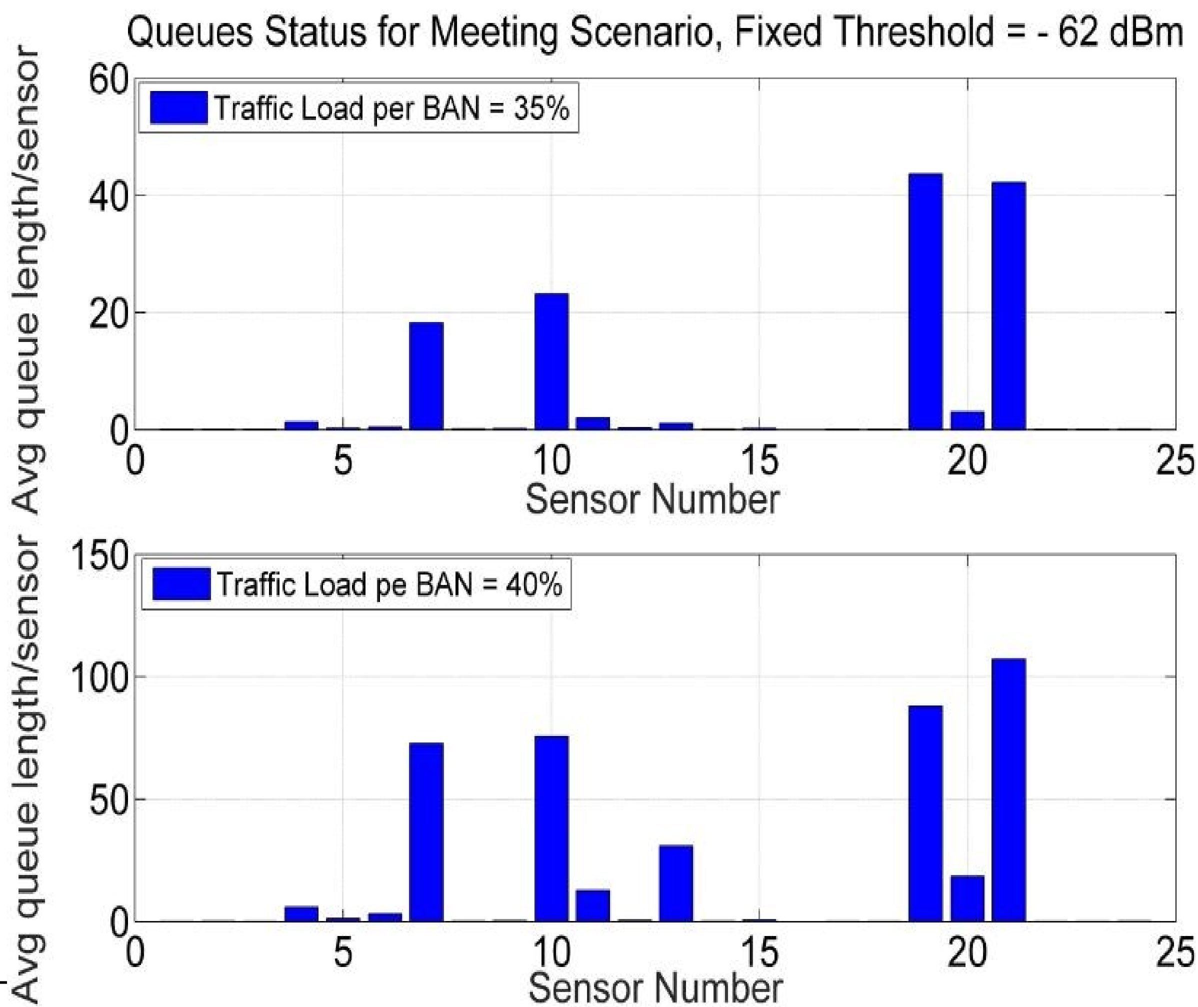
- Similarly, packet drop rate per link can be computed as:

$$\frac{\#PacketsDropped/Link}{\#PacketsDropped/Link + \#PacketsSuccessfullyReceived/Link}$$

Fixed ED Threshold: Average Packet Delay vs Traffic Load for the Static Scenario



Average queue size per sensor for different Traffic Loads



Low Complexity Adaptive Schemes

A) Set the ED threshold equal to the average sensed interference over the past m SFs $(m = 1,2,3, \dots..)$

$$EDT_n = \frac{1}{m} \sum_{i=(k-1)\times m}^{k\times m-1} I_{SF_i}$$

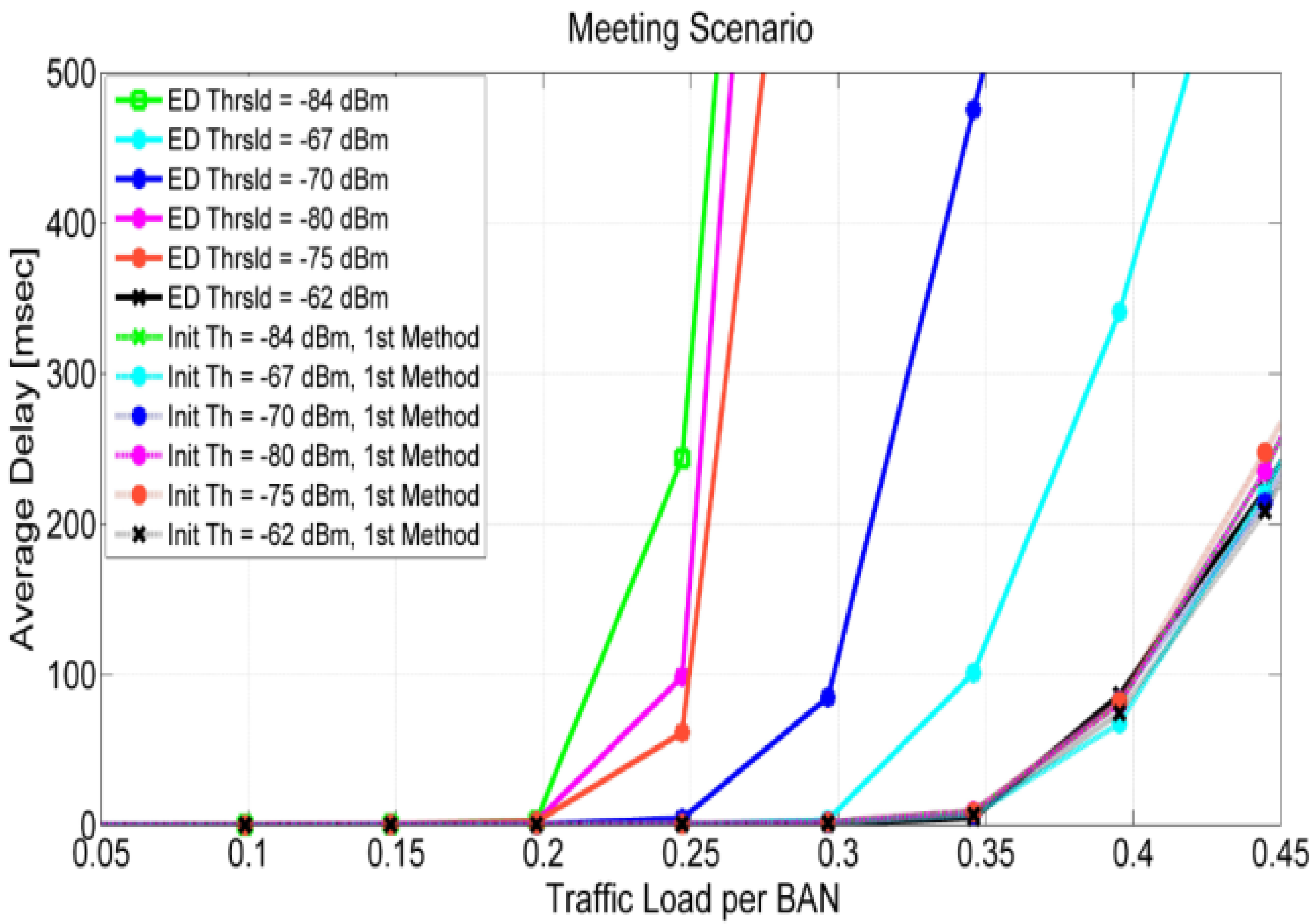
B) Using a sliding window, measure the total interference over m consecutive SFs $(m = 1,2,3, \dots.)$, and set the ED threshold equal to the average sensed interference over the past m SuperFrames.

$$EDT_n = \frac{1}{m} \sum_{i=n-1-m}^{n-1} I_{SF_i}$$

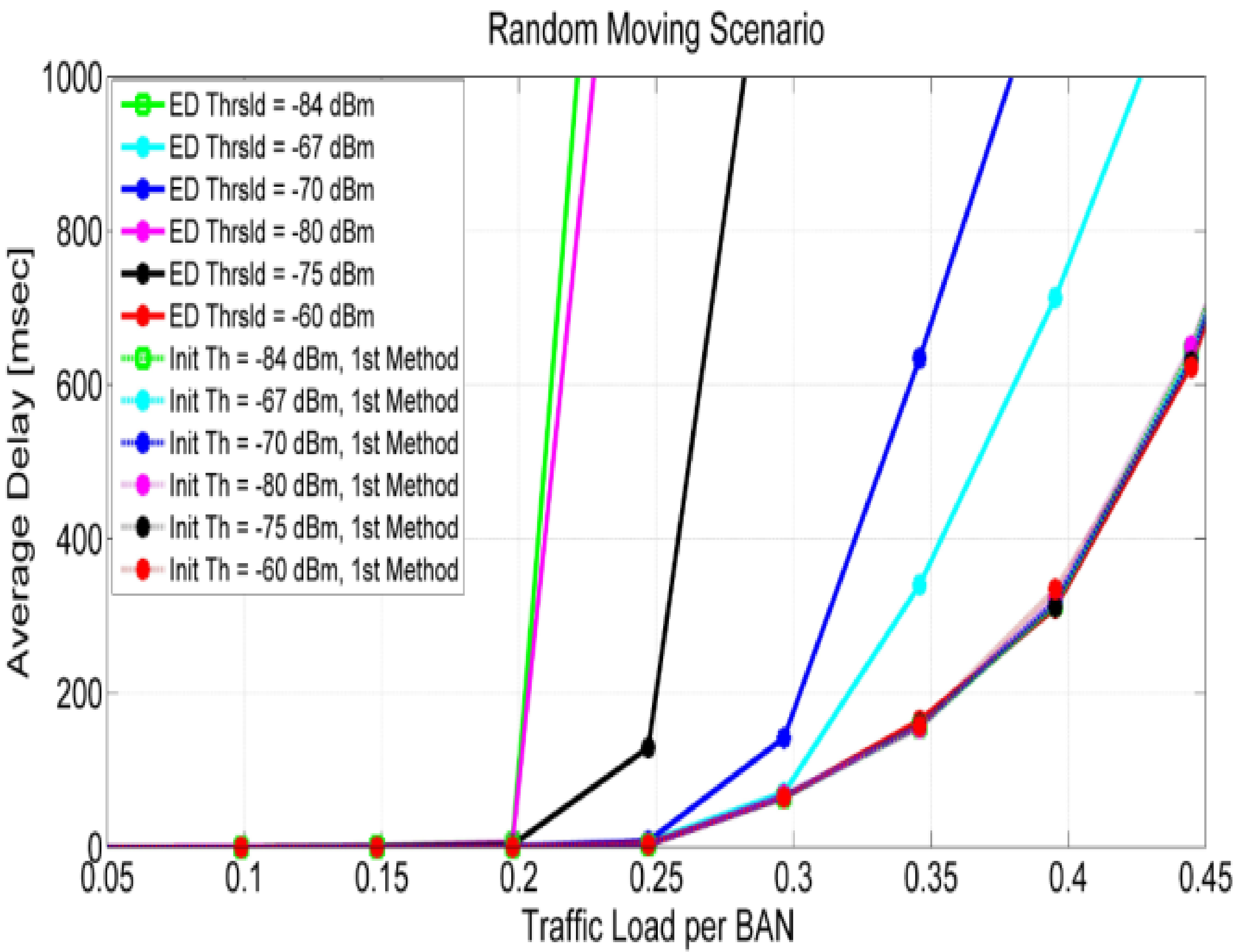
C) Set the ED threshold to be used at SuperFrame n according to the following moving average formula

$$EDT_n = (1-\beta) EDT_{n-1} + \beta I_{SF_{n-1}}$$

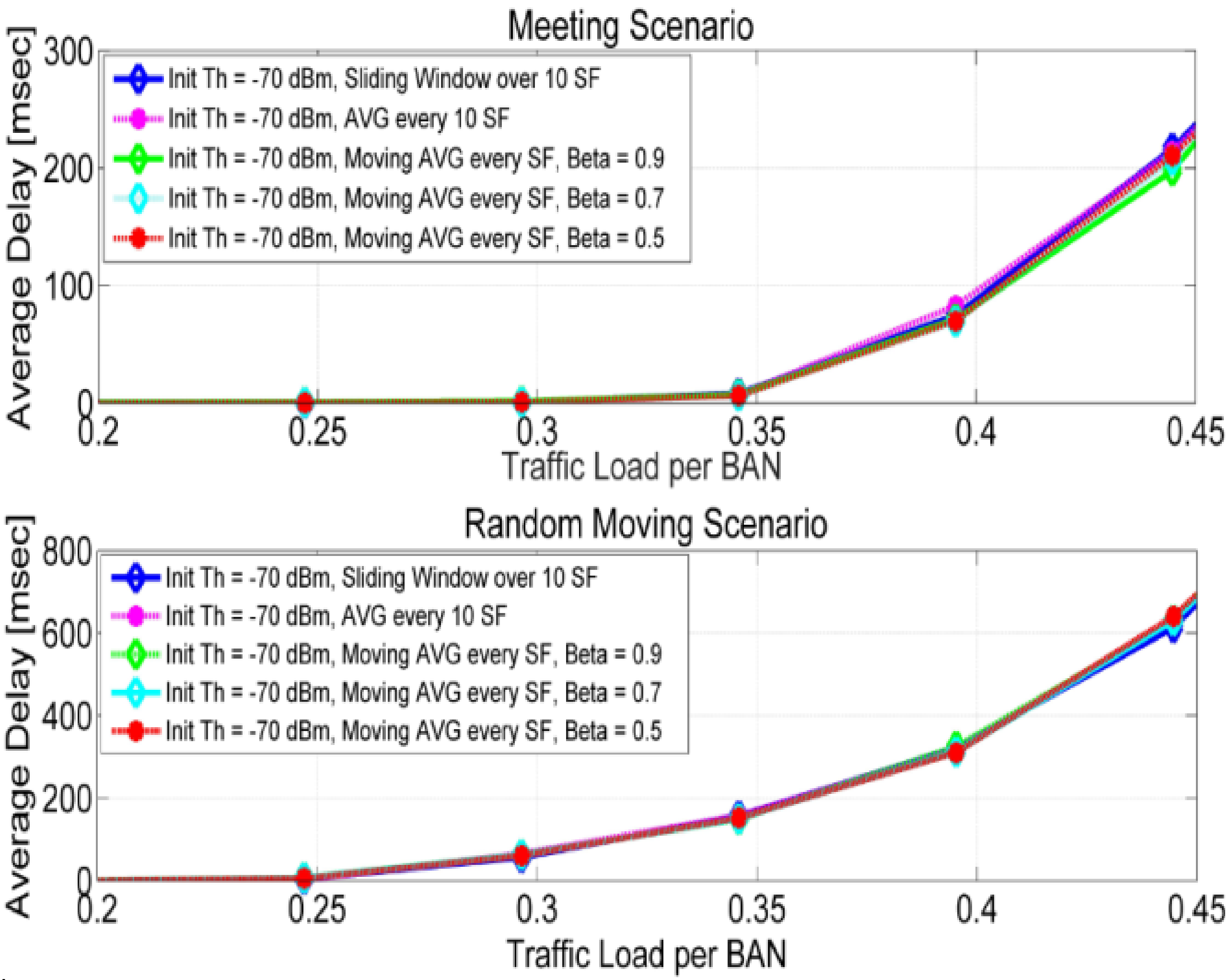
Average Packet Delay vs Traffic Load for the Meeting Scenario



Average Packet Delay vs Traffic Load for the Random Moving Scenario



Average Packet Delay vs Traffic Load for different adaptive strategies



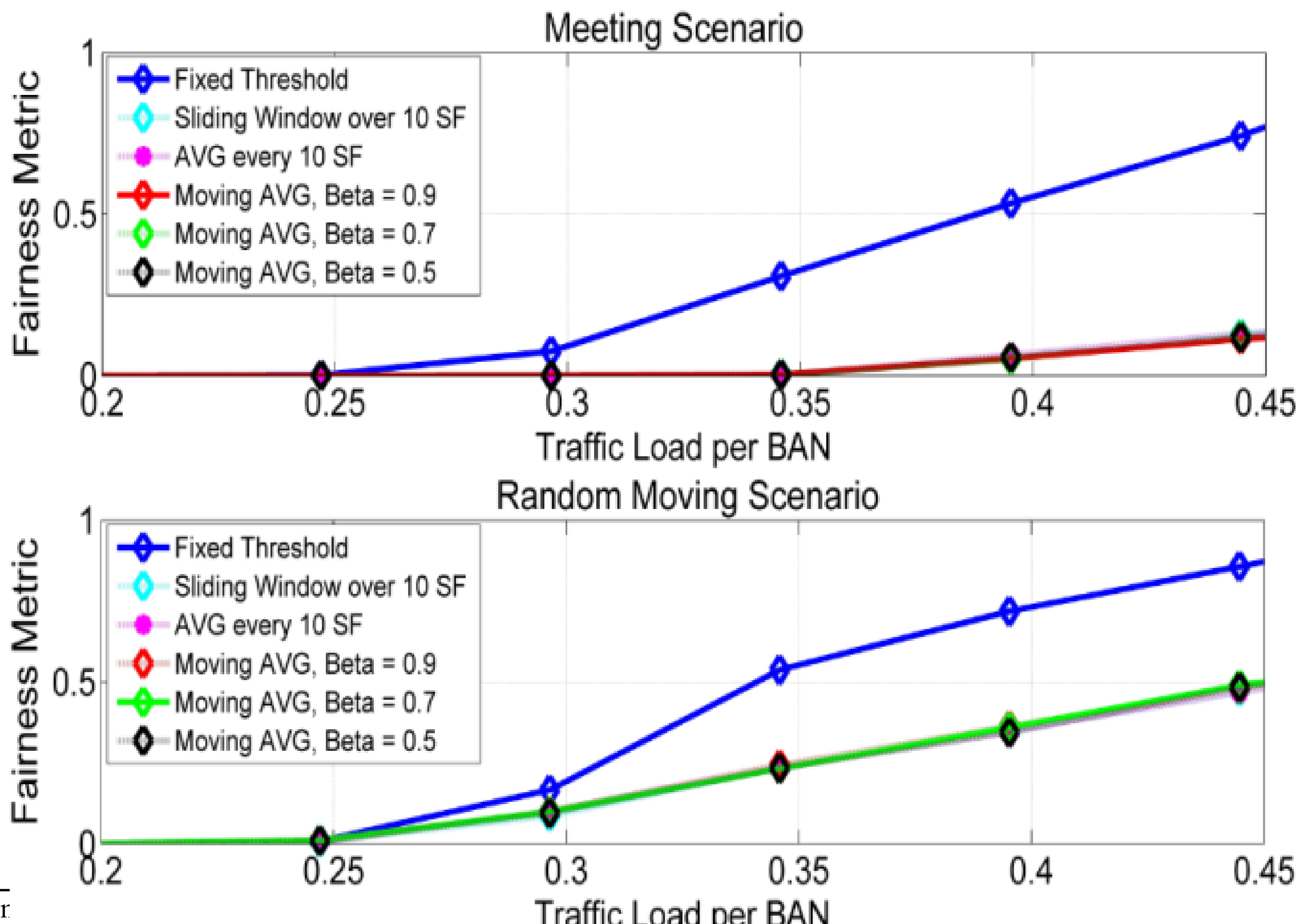
Average Packet Delay vs Traffic Load for different adaptive strategies

To measure fairness among the links in each multi-BAN scenario, we have also defined the following metric:

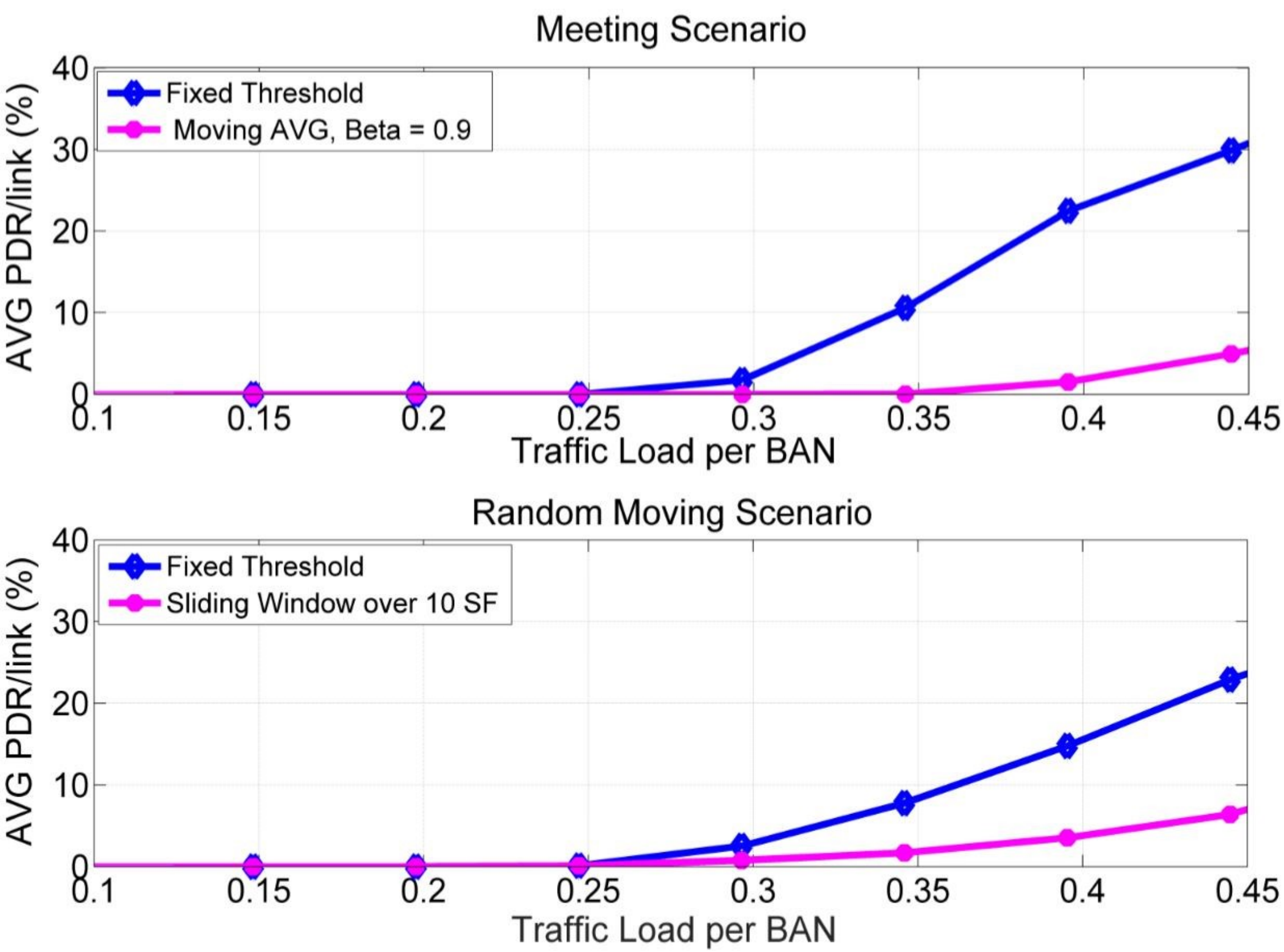
$$Std\ (\frac{Average\ Queue\ Size\ at\ Transceiver\ i}{Average\ Interference\ at\ Transceiver\ i})$$

where $Std(.)$ denotes the standard deviation of the ratios of the average queue size at each transmitting node to the average interference that the node has experienced.

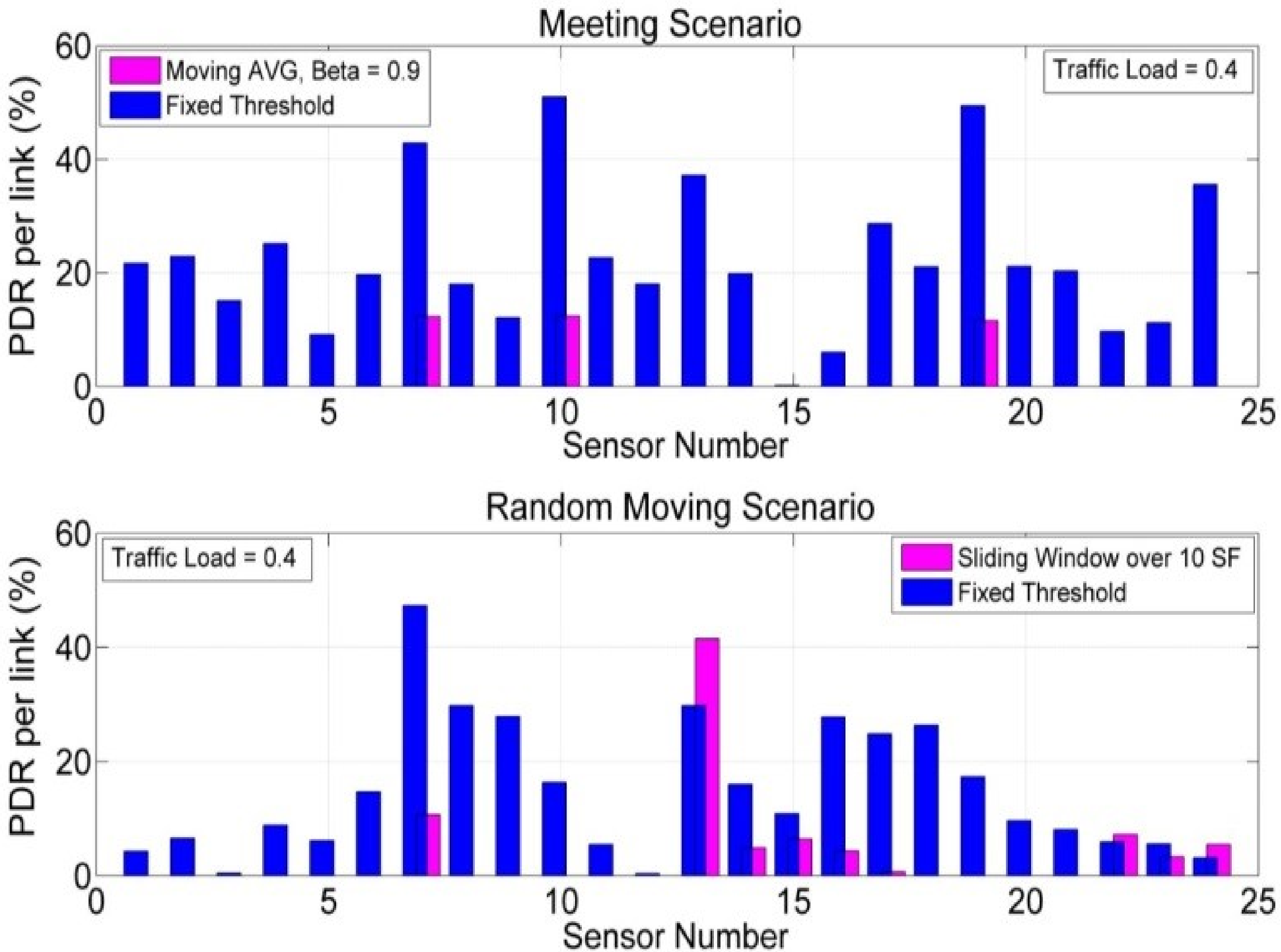
Fairness for Meeting and Random Moving Scenario with different adaptive strategies



Packet Drop Rate vs Traffic Load for Meeting and Random Moving Scenario



Histogram of the PDR per link for meeting and random scenarios (Traffic Load=0.4)



Conclusions

- Compared to the common static ED threshold, our simulations suggest that simple adaptive strategies result in significant improvements in average packet delay, packet drop rate and fairness.

- Although the performances of the three proposed methodologies were very close, the choice of the best strategy could be dependent on the exact usage scenario, and the desired performance metric.

- More sophisticated adaptive strategies where information such as channel condition and queue size are taken into account to adjust the ED threshold are also possible but complexity issues may create a challenge in their implementation.

- The ultimate goal of our efforts is developing practical recommendations for implementation or modification of the IEEE 802.16.5 standard.

Reference: M. Barbi, K. Sayrafian, M. Alasti, A Low Complexity Adaptive Algorithm for the Energy Detection Threshold in IEEE802.15.6 CSMA/CA, IEEE Conference on Standards for Communications & Networking (IEEE CSCN 2016), Oct. 31 - Nov. 2, 2016