Application of Information fusion to unreliable wireless sensor networks

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Abstract

Thesis is appropriated analyze to performance metric evaluation for decentralized distributed detection sensor network strategy. Performance metric investigated a typical wireless sensor network with respect to IEEE 802.15.4 standard. Distributed detection is considered with present of the fusion node as long as clustering and non-clustering sensor network. The clusters are organized uniform and non-uniform topology sensor networks with tree-based topologies and hierarchical multi-level fusion centers. Fusion centers are acting as head of cluster for decision making based on majority-like received signal strength (RSS) with comparison an optimized threshold with concerning to channel influence. FCs decisions will forward to Access point (AP). AP behaves similar as a fusion node with same channel affect but in next level of fusing. Decision error probability at Fusion node is taken into the account based on ideal and non-ideal channel with Channel State Information (CSI) impacts. Network average delay, Reliability, Packet failure, Energy consumption, Network aggregation throughput are considered as performance metric parameters versus packets generation rates and two 3,12 (dB) signal to noise ratio. An analytical Markov model IEEE 802.15.4 MAC layer is supposed which characterized the slotted CSMA/CA mechanism of beacon enable mode. Markov model drives the performance metric base on MAC and physical layer cross-layers method and Channel State Information specifications. We assumed the performance metric is evaluated with equation outcome from Markov model with mentioned topology with present of Fusion node. With this combination, a theoretical performance evaluation framework is proposed. Application of fuzzy fusion theory is considered in framework as well. Inference performed with fuzzification, rule evaluation, combination or aggregation of rules, and deffuzification based on most common methods of fuzzy logic Mamdani inference.The two inputs value are the distance of a sensor node from fusion center node (cluster head) and its available RSSI as singnal to noise ratio. Project figured out with simulations of Markov model with proposed framework. Results represent significant enhancement on performance of network and accuracy of received data to fusion nodes actions.

Preface

Information fusion has many applications within different fields of information and communication technology, signal processing, image processing and target tracking, robotic, smart system and smart sensors. Wireless sensor network is one of applicable field of this theory for enhancement of performance, increase accuracy, data recognition, and state estimation. Thesis started with a proposal of thesis project by my great supervisor ,*' Prof. Hamidreza Karimi '* as a part of my study in Master of ICT Mobile Communication at The university of Agder, Faculty of Engineering and Science. Matlab software was my tool to implementation. Thesis causes to learn Matlab deeply. Thank you matlab!

I would like to have appreciation to all my professors in university of Agder Grimstad, particularly my superior professor, and supervisor, *' Prof.Hamid reza Karimi '* who gave me inspiration and explanatory instruction during thesis. I would like to thank to *' Prof.Ole-Christoffer Granmo '* who has been great advisor of all students including me in department of ICT.

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Chapter 1

Introduction

In the recent years, employments of Wireless Sensor Networks (WSNs) are increased in many aspects of modern lifestyle. Those applications are motivated the researchers around world attampt into this field to investigate Quality of Service (QoS) and performance of network for more efficiency improvement. Usually, wireless sensor networks are supposed to be in harsh environments then performance metric evaluation at the real situation is difficult where human intervention for evaluating process, even maintenance, repair or fix purposes are jeopardy. Hence, performance evaluation based on the mathematical model of network and simulation highly considered. In this way, behavior of network would be predictable with alteration environmental parameters or standards. Measured parameters which applied in performance metric equations, give us possibility to tune them on different situations characteristics and obtain best performance as possible. For example, temperature noise impacts on electrical signal must be taken into the account in monitoring area of process with heat environment surrounding. Mathematical model helps to utilize sensor with better specifications and quality during installation process , likewise, implementation a network topology with best performance , lower-cost and more efficiency.

Basically, with the aim higher performance per cost ratio, efficient mathematical modeling and simulation evaluation are perfect tools before implementation in reality. To address problem, a naval performance evaluation framework would be proposed. Mathematical model framework is studied the interplay between a decentralized detection task in clustered networks and the IEEE 802.15.4 Medium Access Control(MAC) mechanism and Physical layer with cross-layer and channel state association. The framework investigates some strategies for the configuration of WSNs all based on the optimal tuning of sensor node and IEEE 802.15.4 key parameters with present fusion node.Decision making performs based on majority-like reception at fusion node with Maximum-Likelihood Test. Moreover, tree-based topology network implemented with presence clustering. Uniform and non-uniform distribution of sensors in clusters are considered. Distributed sensors are detecting a constant binary phenomenon, in addition Signal to noise ratio(SNR) impacts are surveyed on decision-making at FC with present ideal or non-ideal communication link. On the other hand, IEEE 802.15.4 only is Physical (PHY)/Medium Access Control (MAC) radio interface and has key factors standard for WSNs. PHY and MAC cross-layer methodology is utilized for improve approximation probability of reliability ,packet failure and another performance metric objectives. Also, Channel State Information (CSI) taken into the account as a significant interface actor for both side to carrying generated packet data from multi-sensors detector and transmitter across channel to fusion node.Due to evaluation based IEEE 802.15.4 MAC layer, a Markov chain model is employed which proposed at [18]. Model describes a generalized analytical model of the slotted CSMA/CA mechanism of beacon enabled IEEE 802.15.4 with retry limits for each packet transmission. Model proposed state for a single node with representing three stochastic processes. Markov Model only considered to packet collision probability as case of loss. We consider physical layer and channel state also as a provoking factor to loss, therefore, channel modulation and channel coding are considered when gain of channel computed based on path loss, shadowing and fading effect, signal to noise ratio. performance metric equations in [18]and[10] are used in thesis with some explanation with approach for framework topology and strategy

1.1 Motavation and goals

Functionality of WSNs would be enhanced with designing flexible sensor distribution and taking care to position of whole parameters which contribute to detecting, packaging and transmitting and recognition truly at receiver side. Performance metric evaluates as a method of functionality assessment .In this thesis as a part of my study try to investigate that issue with application information fusion with integration of Markov chain model and also effects of channel state on overall whole network. literature just shows slightly attempt in this enormous technology which covering a small portion of WSN area with considering to pervious attempt ,nevertheless,proposed framework comes into the account as possibility and capability and time limitation for performance evaluation.

1.2 Literature Analysis

At beginning of project, we took a close look on previous efforts and surveyed the literatures with key words, information fusion or data fusion, wireless sensor network and WSN Markov chain model and performance evaluation WSN. Publications and articles found base on our point of view around project. According to our interest documents reviewed and sieved some of them which coming in bibliography section. Authors at [1],represent a technique to find the optimal threshold for the binary phenomena detection problem with identical and independent distributed sensors , based their approach, the probability of error is based on a quasi-convex function of threshold and they assumed the fusion center makes a global decision based on the local binary decisions.Authors of publication[2] are investigated wireless sensor networks with a small amount of sensors and low Signal to Noise Ratio , distributed detection and decision making fusion rules based on multi-bit knowledge of local detecting sensors with Monte-Carlo simulation methods to study the performance of proposed decision fusion rules with parameters such as Rayleigh fading channel and adaptive Gaussian noise. At significant literature [3], researchers present a mathematical model for estimate probability of error detection to studying decentralized detection in clustered wireless sensor networks, in this paper proposed sensors that distributed with the aim of detecting an event of interested sensors and fusion centers (FCs) as fuser of received data which are organized in clusters topology, with FCs acting as cluster heads, and are supposed to observe the same common binary phenomenon. With this design also the medium access control (MAC) protocol are defined by the standard, based on carrier-sense multiple access with collision avoidance. Decentralized detection and MAC issues are jointly investigated through analytical modeling.In [5],[8] authors with respect to similar field of efforts at [3], proposed a simulation-based analysis of the impact of data fusion mechanisms in a Zigbee sensor network used to monitor a as particular constant binary phenomenon and evaluated performance indicators of interest .e.g. Bit Error Rate (BER) and networking oriented (throughput, delay, and aggregate throughput), however, decentralized detection in clustered sensor networks with hierarchical multi-level fusion, respectively. At [7,21] a distributed detection (DD) system assumed , multiple sensors/detectors work collaboratively and the fusion center is responsible for the final decision-making task based on information gathered from local sensors, the integration of wireless channel conditions in algorithm design taken into the account.At [9] important channel dynamic well defined and gave significant idea for this thesis, their studies is represented the behavior of a real link impact in low-power wireless networks. In particular, there is a large transitional region in wireless link quality that is characterized by significant levels of unreliability and asymmetry, significantly impacting the performance of higher-layer protocols. They provide a comprehensive analysis of the root causes of unreliability and asymmetry and derived expressions for the distribution, expectation, and variance of the packet reception rate as a function of distance, as well as for the location and extent of the transitional region. In this thesis, we will use some of expressions with correlation our approach. At [10,14,18] authors proposed a generalized analysis of the IEEE 802.15.4 medium access control (MAC) protocol in terms of reliability, delay and energy consumption. The IEEE 802.15.4 exponential backoff process is modeled through a Markov chain taking into account retry limits, acknowledgements, and unsaturated traffic. Simple and effective approximations of the reliability, delay and energy consumption under low traffic regime .Proposal Markov chain is using on our thesis and our performance metric evaluation figure out with expanding this Markov chain in framework our proposal with high traffic data generation ragime [25]. books and online documents available in internet were surveyed. Wikipedia database was a great help to access necessary information quickly.

1.3 Thesis outline

Thesis is structured in five chapters which are comprising theoretical , thesis framework and simulated results. Conclusion of thesis will be coming in last chapter. Main contents of contribution topics are organized in next chapters are as following:

- Chapter two includes fundamental theory which we will be encountering during whole thesis steps. This begins with a brief description of wireless sensor networks and their nodes and functionality of them, possible distribution topology with respect to duty of nodes as coordinator or FFD, nodes or RFD.IEEE 802.15.4 two layers investages.Physical layer activities and data units are described summarily with modulation format,radio frequency and other physical specifications.Medium access control channel layer briefly is investigated with respect to CSMA/CA mechanism. Markov chain model for CSMA/CA MAC layer which will be using it expressions for our framework is described.Data fusion theory and schematic diagram fuzzy fusion also are contributed.

- Chapter three includes performance evaluation framework .This chapter describes method of derivation performance which employed in our scenario and its restriction. Initially, parallel fusion architecture is defined, however, secondly clustering topology for decentralized distribution detection with present of parallel fusion architecture into the each cluster with uniform and non-uniform sensors distribution is considered. Expressions of markov chain model described in chapter two extend to new topology and rewrite the expressions based on our framework approach.A summary data fusion is given with short description of methodologies.Fuzzy membership function (FMF) would be described at last part of chapter.

- Chapter four includes simulation results of descripted framework in chapter three. Results would be coming in three parts : first part characterizes basic issues such as the bit generations with OQPSK modulation schemes with different SNR, Second part represents the probability of error decision at fusion nodes in appropriated topology and third part would be shown results of performance metric based on extended Markov chain model.sensor network coverage is presented as function of distance and SNR that implemented base on fuzzy system.

- Chapter five belongs to conclusion results and thesis results, we will have a discussion about consequence and possible new ideas at further works section.

Chapter 2

Fundamental Theory

In this chapter we briefly establish fundamental theory which facing during thesis. Basically WSN parameters description would be discussed as well as topology ,mechanisms and MAC Markov chain model. Utilization of data fusion rules will explain. The Chapter organized in three sections. Section one has a summary of WSNs with focusing on IEEE 802.15.4 first two, Medium Access Channel (MAC) and Physical Layer (PHY).Markov chain model would be explained within Section two. Its expressions for performance metric considered and also requirements. A conceptional explanation gives about information fusion in section three in general as well as our fusion scenario methods.

2.1 Wirelss Sensor Networks

In general, Wireless sensor network(WSN) identifies numbers of collection sensors with integration by a radio transceiver for generating, processing and packaging sensed phenomena under observation as data packets and transmitting via wireless channels to a sink or Access Point (AP) or coordinator or a neighbor node as first destination. Every sensor with transceiver named a node or device. There are two types of device. Full Function Devices (FFDs) and reduced-function devices (RFDs). An FFD is able to accept any roles in the network. An RFD has restricted capabilities, for example, FFD can communicate with any nodes but RFD just can communicate with FFD. Possible topology of nodes base on monitoring phenomena represent at Figure2.1.

Star, peer-to-peer (mesh), and hybrid cluster-tree are shown .In the star or centralized topology, every node in the network can communicate only with the network sink or coordinator. A typical scenario in a star network configuration is a FFD that configured to be a coordinator in the network. A coordinator is to select a unique identifier that is not used by any other network in its radio sphere of influence in the location surrounding. In a peer-to-peer or decentralized topology each node able to communicate directly with any other node which node are located close enough to establish a successful wireless radio link. Each FFD in a peer-to-peer topology network can act the role of network coordinator. RFDs can communi-

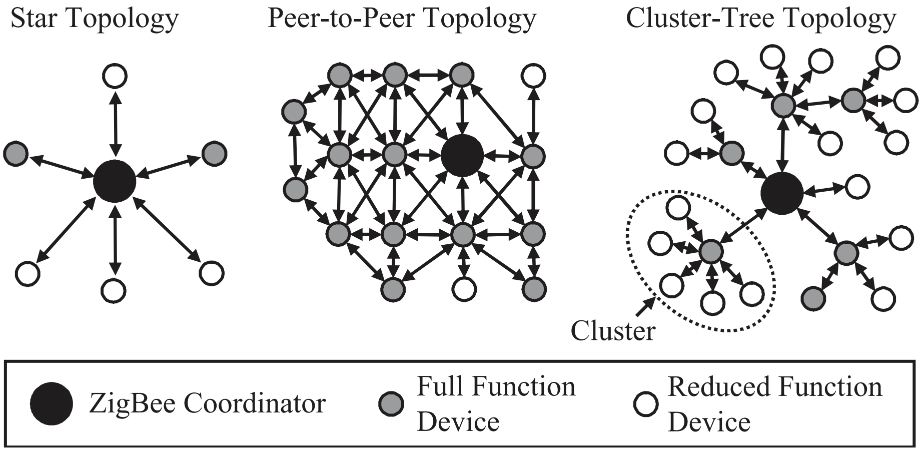

Figure 2.1: The Possible topology of nodes base on observing event

cate with each other and coordinator. Dynamic routing data through nodes using by multiple hops, network coverage can be extended even far longer than a radio range[24]. A cluster-tree or hybrid network topology is able to complex self-organizing network topologies. This network is a combination of star and peer to peer topologies. The network consists of clusters, each having a network FFD node as a cluster head for routing and data aggregator and multiple RFD nodes as group of end devices as leaf at cluster. Head of cluster communicate with the network coordinator that acts as a root. The network is formed by parent, child relationships, where RFD nodes associate as children with the existing header. A network coordinator may instruct a new child to become the head of a new cluster. Otherwise, the child operates as an end RFD device [4][24]. There are number of standardizations body for WSNs, however, IEEE standardized two lower layers, Medium Access Control (MAC) and Physical (PHY) layers which specified with IEEE 802.1.5.4. The upper layers identify based on Open System Interconnect (OSI) basic reference model e.g. ZigBee standard.layers are shown in Figure2.2.

IEEE 802.15.4 was developed independently of the ZigBee standard and other existence standard, it is possible to build short-range sensor wireless networking based exclusively on IEEE 802.15.4 and not implement ZigBee-specific layers. In this case, we develop own wireless networking independent from Zigbee upper layer protocol and based on IEEE 802.15.4 PHY and MAC layers. However, results are usable for Zigbee and other standards.

2.2 IEEE 802.15.4 Technology

The IEEE 802.15.4 wireless technology is a short-range, low-cost, low-power consumption communication system designed for provide applications with relaxed throughput and latency requirements in Wireless Personal Area Networks (WPANs). The key features of the IEEE 802.15.4 wireless technology are low complexity to be supported by cheap devices . The IEEE

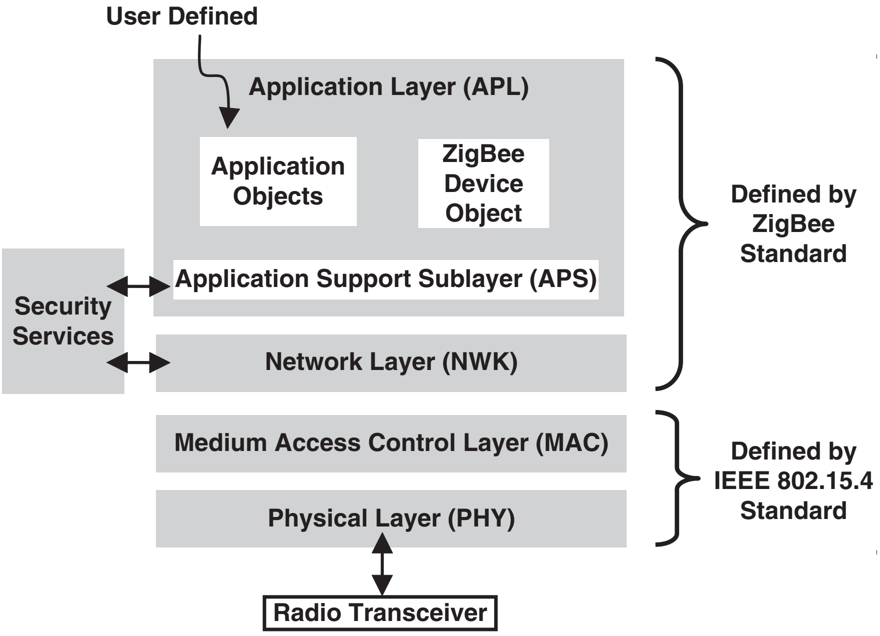

Figure 2.2: The IEEE 802.15.4 and ZigBee wireless networking layers contrast

802.15.4 focuses on the standardization of the bottom two layers of ISO/OSI protocol stack: Physical (PHY) and MAC.

2.2.1 IEEE 802.15.4 Physical Layer

The physical layer is interface with the physical medium. It is responsible such as the receiver sensitivity and the transmitter output power, radio transceiver activation and deactivation, energy detection (ED), link quality, clear channel assessment (CCA), channel selection, and transmission and reception of the message packets.

Channel Assignments:

The IEEE 802.15.4 standard specifies a total of maximum 27 half-duplex channels page across the three frequency bands, the frequency channels are simply identified by channel numbers. The Table 2.1 shows channel assignment , channel pages and Modulation .

- The 868 MHz band, ranging from 868.0 to 868.6 MHz and used in the European area, uses a raised-cosine-shaped Binary Phase Shift Keying (BPSK) modulation format, with DS-SS at chip-rate 300 kchip/s (a pseudo-random sequence of 15 chips transmitted in a 25 us symbol period). Only a single channel with data rate 20 kbit/s is available and, with a required minimum -92 dBm Radio Frequency(RF) sensitivity, the ideal transmission range [4,24].

Frequency (MHz)	Number of Channels	Modulation	Bit Rate(Kb/s)	Spreading Method
868-868.6	1	BPSK	20	Binary DSSS
902-928	10	BPSK	40	Binary DSSS
2400-2483.5	16	O-QPSK	250	16-array orthogonal

Table 2.1: IEEE 802.15.4 Data Rates and Frequencies of Operation[24]

- The 915 MHz band, ranging between 902 and 928 MHz and used in the North American and Pacific area, uses a raised-cosine-shaped BPSK modulation format, with DS-SS at chip-rate 600 kchip/s (a pseudo-random sequence of 15 chips is transmitted in a 50 us symbol period). Ten channels with rate 40 kbit/s are available and, with a required minimum -92 dBm RF sensitivity [4,24].
- The 2.4 GHz Industrial Scientific Medical (ISM) band, which extends from 2400 to 2483.5 MHz and is used worldwide, employing a half-sine-shaped Offset Quadrature Phase Shift Keying (O-QPSK) modulation format, with DS-SS at 2 Mchip/s (a pseudo-random sequence of 32 chips is transmitted in a 16 us symbol period). 16 channels with data rate 250 kbit/s are supported with minimum -85 dBm RF sensitivity required, the ideal transmission range is approximately 200 m [4,24].

Energy detection:

The energy detection (ED) happens when device plans to transmit a message goes into the receive mode to detect and estimate the signal energy level in the desired channel. The ED procedure might not be able to detect weak signals with energy levels close to the receiver sensitivity level.The IEEE 802.15.4 allows 10 dB differences between the required receiver sensitivity level and the required energy detection level[24]. Therefore, ED must be detecting sufficient level in mentioned tolerance. The MAC requests the PHY to perform ED.

Clear Channel Assessment:

The One of cooperation between PHY layer and MAC layer defines in clear channel assessment. Meduim Access Channel mechanisms , particularly requires to perform clear channel assessment (CCA)which ensure channel does not occupy with another node[4].This management prevents to collision in channel but does not guaranty.The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) channel access mechanism, working based on CCA.The CCA decision made by concluding from energy detection(ED) or Carrier Sense (CS) whether frequency channel should be considered available or busy[24].

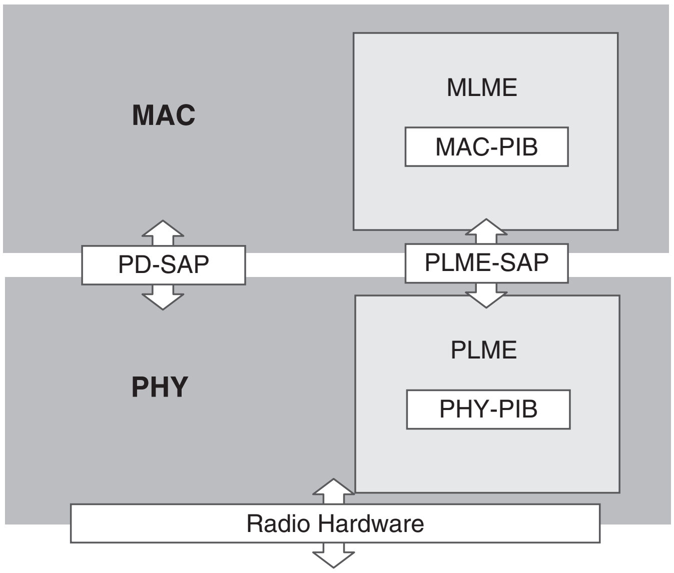

Figure 2.3: The IEEE 802.15.4 PHY Reference Model Interfacing the MAC Layer

PHY Packet Format:

The PHY Protocol Data Unit (PPDU) format consists of three components ,the Synchronization header (SHR), the PHY header (PHR), and the PHY payload.A synchronization header (SHR), which enable the synchronization with the sequance bit stream. It is including of a preamble field, used by the transceiver to obtain chip and symbol synchronization, and the start-of-frame delimiter (SFD), which indicates the end of the SHR and the start of the data packet [24].A PHY header (PHR), which contains the frame length.The PHY payload with a variable length depending on the MAC sublayerframe[4].the PHY packet shown in Figure 2.4.The MAC sublayer frame packages into the Phy layer packet and send.

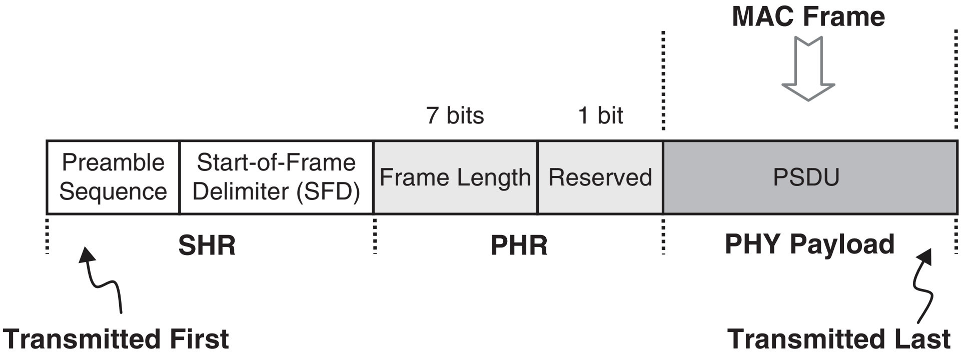

Figure 2.4: PPDU Format

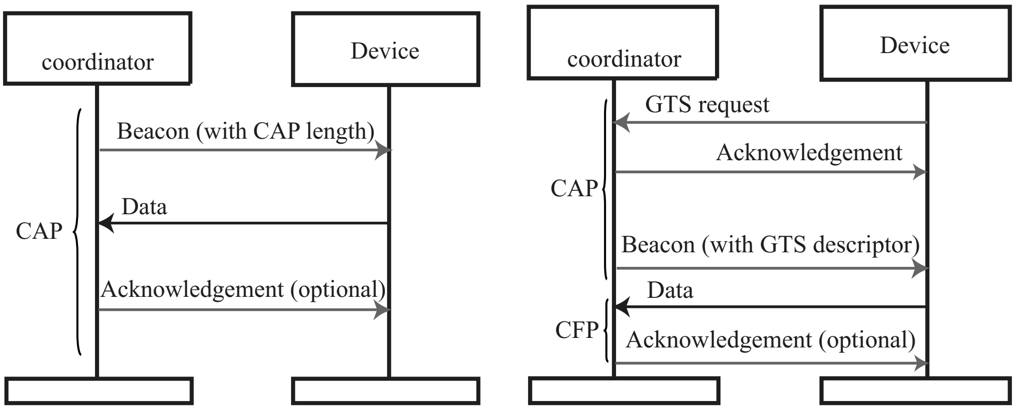

Figure 2.5: Data transfer of beacon-enabled during the CAP and CFP

2.2.2 IEEE 802.15.4 MAC Layer

The Maduim Access Control provides the interface between the PHY and the next higher layer above the MAC and shared channel and reliable data delivery.IEEE 802.15.4 uses the CSMA/CA algorithm for access meduim[4].MAC based on this mechanism must be awar about ongoing transmition then listening to the channel before transmitting with assocation PHY layer and doing CCA to reduce the probability of collisions with other ongoing transmissions[24].The major action which performed by the MAC sublayer are: association and disassociation,optional star network topology functions with generation and Guaranteed Time Slots,beacon (GTSs) management, generation of ACK frames and security contorl.The IEEE 802.15.4 two operational types defined for MAC which corresponding two different mode of performing for CSMA/CA.Two methods namely are beacon-enabled and non beacon-enabled.

The non beacon-enabled mode nodes use an unslotted CSMA/CA protocol to access the channel and transmit their packets.this scheduling implemanted with a random time that call

backoff periods.Each node preserves two variables for each transmission attempt, the number of times (NB) the CSMA/CA was required to backoff while trying the in the same transmission, this value will be initialized to 0 before each new transmission attempt and it value limited cannot be larger than NB_{max}. the backoff exponent (BE) related to the maximum number of backoff periods ,in range $\{1, \cdots, 2^{BE}\}$, a node will wait before attempting to assess the channel. BE is initialized to the value of BE_{min} and cannot assume values larger than BE_{max}.While initially variables assigned node start to perform the sensing the channel for beginning transmission.

The beacon-enabled mode nodes use a slotted CSMA/CA protocol to access the channel and transmit their packets.In this method instead of variables assignment and manage by them, management performs via superframe ,at beginning a packet, called beacon, transmitted by the coordinator to synchronized the node and activated it for transmitting.The Chart in Figure. 2.6 represents a completely both mode of CSAM/CA protocol. The superframe may contain

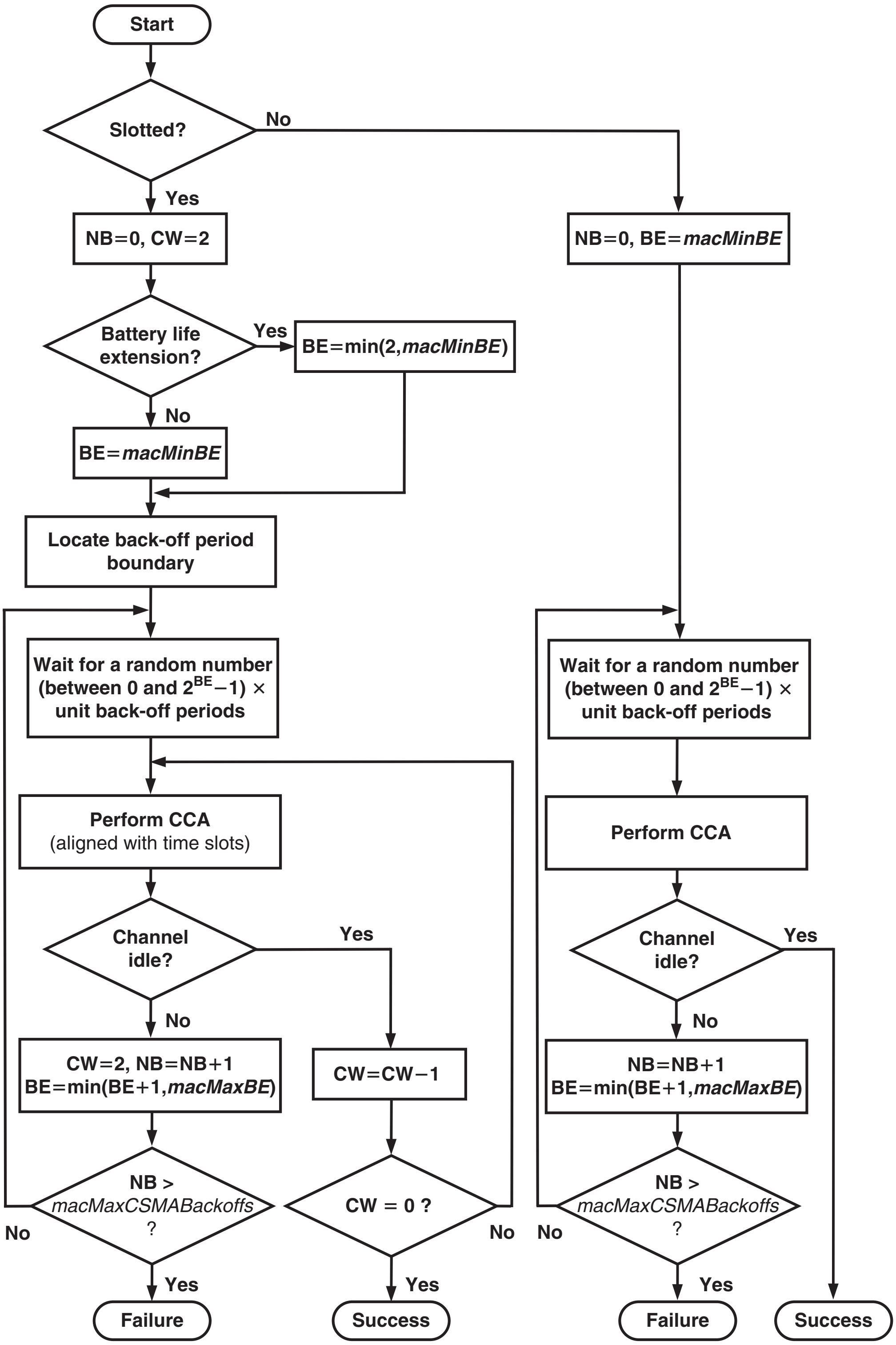

Figure 2.6: The CSMA/CA protocol,beacon-enabled and non-beacon-enabled modes

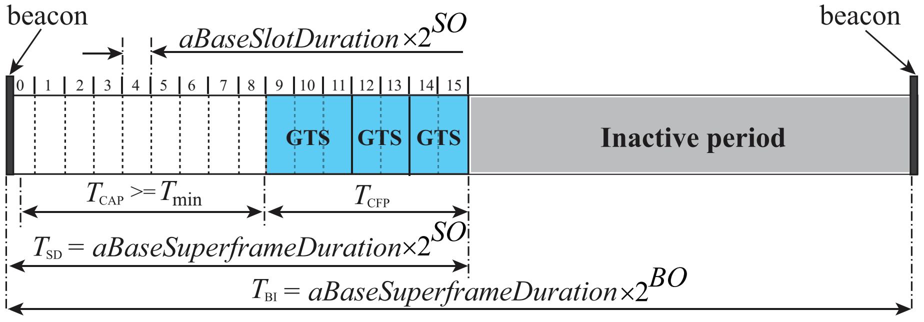

Figure 2.7: Superframe structure of IEEE 802.15.4

an inactive and active parts , during inactive part it is allowing to nodes to go in sleeping mode, whereas during the active part is separate into two parts: the Contention Access Period (CAP) and the Contention Free Period (CFP), combining with GTSs, that can be sent by the coordinator to specific node. the Figure. 2.5 shown communicating data transfering between coordinator and devcie in baecon-enabled mode.A slotted CSMA/CA mechanism is used to access the channel of non time-critical data frames and GTS requests during the CAP . In the CFP, the dedicated bandwidth is used for time-critical data frames[25]. Figure. 2.7 illustrates a superframe structure in beacon-enabled mode.The structure of the superframe is defined by two parameters, the beacon order (BO) and the superframe order (SO), which determine the length of the superframe and its active period, respectively, they are given by,

$$T_{BI} = aBaseSuperframeDuration \times 2^{BO},$$

$$T_{SD} = aBaseSuperframeDuration \times 2^{SO},$$

2.3 Analytical Markov chain model IEEE 802.15.4

So far, we gathered general knowledge about WSN and PHY and MAC layer .Now, we present an analytical Markov chain model which has significant role in performance metric evaluation framework that would be illustrated in the next chapter. Markov model is considering a star network with a coordinator, and N nodes transmitting toward the coordinator. These nodes use the beacon-enabled slotted CSMA/CA and ACK. The parameters of the CSMA/CA protocol use to represent how influence on performance metric e.g. reliability, delay and energy consumption. supposing that the network generates an unsaturated traffic, which is a natural scenario for many WSN applications [10].

Three stochastic processes s(t), c(t) and r(t) are representing the backoff stage, the state of the backoff counter and the state of retransmission counter at time t, respectively. Figure 2.8 shows the Markov model graphically [25].In Model assumes independent probability that nodes start sensing, the stationary probability τ is a probability of a node attempts a first carrier sensing in a randomly chosen slot time is constant and independent from other nodes. The three dimensional Markov model defined with tuple ((s(t), c(t), r(t)). Some key MAC parameters denotes , $W_0 \triangleq 2^{macMinBE}$,$m_0 \triangleq macMinBE$,$m_b \triangleq macMaxBE$, $m \triangleq macMaxCSMABackoffs$,$n \triangleq macMaxFrameRetries$ [18]. The states of node transition posteriori probabilities are indicated based on three key probabilities that measured τ,α and β which are represent the probability of a node attempts a first carrier sensing, the probability of finding busy channel in (CCA1), represents the probability of finding busy channel in (CCA2) ,respectively.for timing duration of the ACK fram,ACK timeout,interfram spacing(IFS),data packet and header length the L_s,the packet successful transmission time, $L_c$the packet collision time, given as :

$$L_s = L + t_{ack} + L_{ack} + IFS,$$

$$L_c = L + t_{m,ack},$$

where, L is the total length a packet with overhead and payload,t_{ack} is ACK witaing time,L_{ack} is length ACK frame,$t_{m,ack}$ is timeout of ACK[14,25].

Particularly,we need essential CSMA/CA protocol statistics for The performance metric evaluation expressions that Model is given based on MAC parameters.
Initially,notation for MAC parameters are as follow:

$$W_0 \triangleq 2^{macMinBE},$$

$$m_0 \triangleq macMinBE,$$

$$m_b \triangleq macMaxBE,$$

$$m \triangleq macMaxCSMABackoffs,$$

$$n \triangleq macMaxFrameRetries,$$

The probability τ that a node attempts a first carrier sensing(CCA1) in randomly chosen time slot is [18]:

$$\tau = \left(\frac{1 - x^{m+1}}{1 - x}\right)\left(\frac{1 - y^{n+1}}{1 - y}\right)\tilde{b}_{0,0,0} \tag{2.1}$$

where,approximation of state probability is :

$$\tilde{b}_{0,0,0} \approx \frac{W_0}{2}(1 + 2x)(1 + y) + L_s\left(1 - x^2\right)(1 + y) + \tag{2.2}$$

$$K_0\left(\left(P_c\left(1 - x^2\right)\right)^2\left(\left(P_c\left(1 - x^2\right)\right)^{n-1} + 1\right) + 1\right)^{-1}$$

and,P_c,probability of transmitted packet encounter collision when N is number of whole nodes

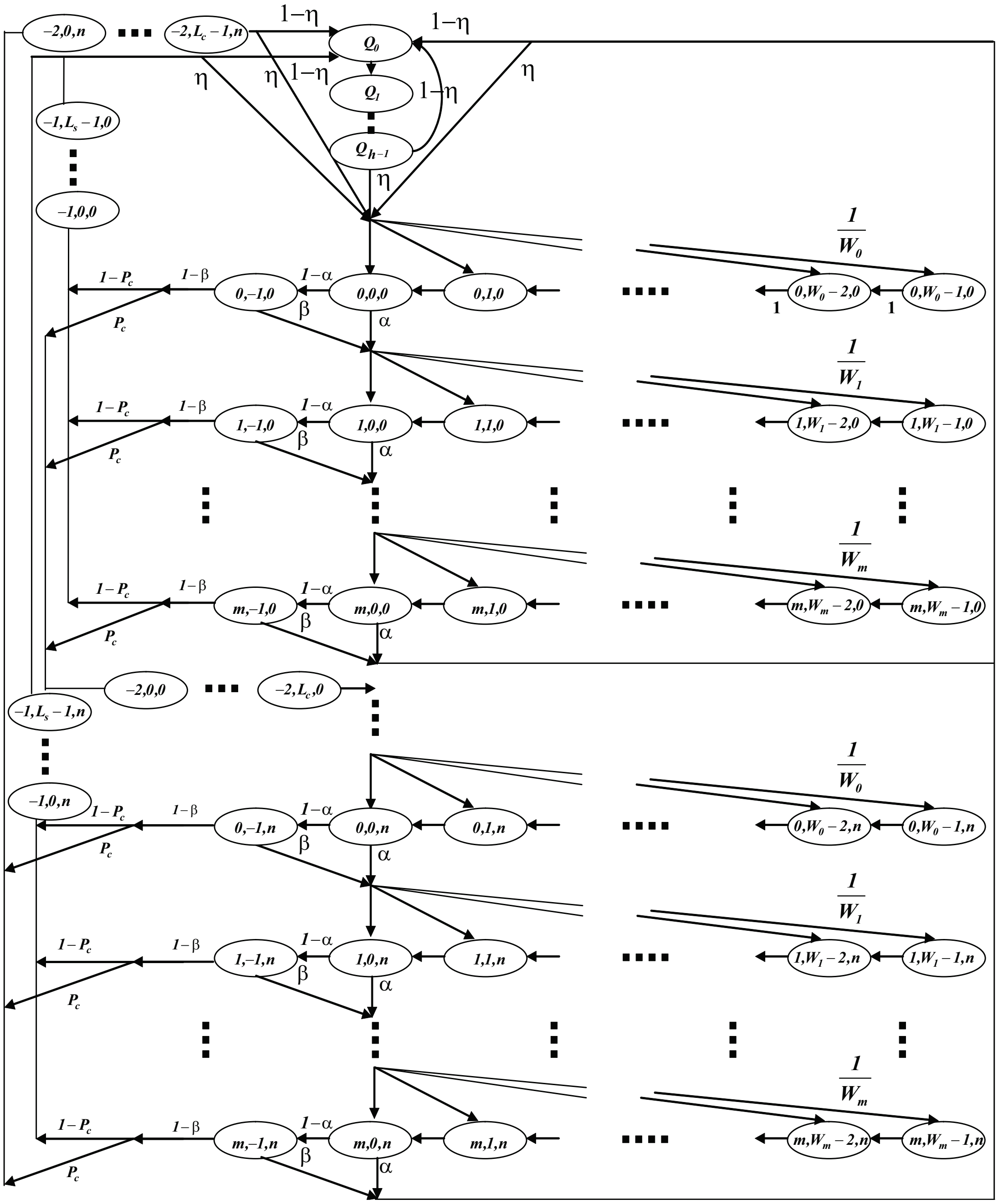

Figure 2.8: Markov chain model for CSMA/CA of IEEE 802.15.4

is given:

$$P_c = 1 - (1-\tau)^{N-1} \tag{2.3}$$

also, $K_0 = L_0 q_0/(1-q_0)$ whereas, L_0 is the idle state length without generating packets and,q_0 is the probability of going back to the idle state[18].

$$x = \alpha + (1-\alpha)\beta \tag{2.4}$$

$$y = P_c\left(1 - x^{m+1}\right) \tag{2.5}$$

The busy channel probabilities (CCA1) and (CCA2) are α , β respectively, given as follows:

$$\alpha = \alpha_1 + \alpha_2 \tag{2.6}$$

where,

$$\alpha_1 = L\left(1 - (1-\tau)^{N-1}\right)(1-\alpha)(1-\beta) \tag{2.7}$$

and,

$$\alpha_2 = L_{ack}\frac{N\tau(1-\tau)^{N-1}}{1-(1-\tau)^N}\left(1 - (1-\tau)^{N-1}\right)(1-\alpha)(1-\beta) \tag{2.8}$$

also,β is:

$$\beta = \frac{1-(1-\tau)^{N-1} + N\tau(1-\tau)^{N-1}}{2-(1-\tau)^N + N\tau(1-\tau)^{N-1}} \tag{2.9}$$

2.3.1 Performance evaluation expressions

In this subsection, perfeormance metric experssions would be given based on Markov chain model equations 2.1 to 2.9 .Regarding to our senario that coming in next chapter,we will use all of those experssions , constant values and MAC parameters for implemantion and simulation performance evaluation with new approach.

Reliability:

The probability of successful packet reception calls Reliability that obtian as:

$$\mathbf{R} = 1 - P_{cf} - P_{cr} \tag{2.10}$$

Where,P_{cf} is the probability that the packet is discarded due to channel access failure,

$$P_{cf} = \frac{x^{m+1}\left(1-y^{n+1}\right)}{1-y} \tag{2.11}$$

And,P_{cr} is The probability of a packet being discarded due to retry limits,

$$P_{cr} = y^{n+1} \tag{2.12}$$

Average delay:

The average delay for a successfully received packet is defined as the time interval from the instant the packet is at the head of its MAC queue and ready to be transmitted, until the transmission is successful and the ACK is received[14,18,25], ,given by,

$$\mathbb{E}[\tilde{D}] = \mathbf{P}^T\mathbf{D} \tag{2.13}$$

where,$\mathbf{P} = [Pr(A_0|A_t) \cdots Pr(Pr(A_n|A_t)]^T \in \mathbb{R}^{(n+1)\times 1}$, $\mathbf{D} = [d_0 \cdots d_n]^T \in \mathbb{R}^{(n+1)\times 1}$,
$d_j = T_s + jT_c + (j+1)\mathbb{E}[\tilde{T}]$, $j \in \{0, \cdots, n\}$.

$$Pr(A_j|A_t) = \frac{P_c^j\left(1 - x^{m+1}\right)^j}{\sum_{k=0}^{n}\left(P_c\left(1 - x^{m+1}\right)\right)^k} = \frac{\left(1 - P_c\left(1 - x^{m+1}\right)\right)P_c^j\left(1 - x^{m+1}\right)^j}{1 - \left(P_c\left(1 - x^{m+1}\right)\right)^{n+1}} \tag{2.14}$$

$$\mathbb{E}[\tilde{T}] = 2T_{sc} + \sum_{i=0}^{m}\tilde{P}(B_i|B_t)\sum_{k=0}^{i}\left(\frac{W_0 2^k - 1}{2}S_b + 2T_{sc}k\right), \tag{2.15}$$

where,$\tilde{\mathbf{P}} = \left[\tilde{P}(B_0|B_t) \cdots \tilde{P}(B_m|B_t)\right]^T \in \mathbb{R}^{(m+1)\times 1}$, $\mathbf{T} = [t_0 \cdots t_m]^T \in \mathbb{R}^{(m+1)\times 1}$,
,$t_i = [(2^{i+1} - 1)W_0 + 3i - 1]/4$.

$$\tilde{P}(B_i|B_t) = \frac{max(\alpha, (1-\alpha)\beta)i}{\sum_{k=0}^{m} max(\alpha, (1-\alpha)\beta)^k}, \tag{2.16}$$

where, $T_{sc} = S_b$ is the time unit aUnitBackoffPeriod.$T_s = (L_s/g) + aturnaroundTime + aUnitBackoffPeriod + (L_{ack}/g)$ is length successful transmission priod with data rate $g(bps)$. $t_c = L_c/g$ is collid time slot in seconds.

Network aggregate throughput:

$$\mathbf{S} = g \cdot A \cdot L_s \cdot N \cdot \mathbf{R} \tag{2.17}$$

where,$\mathbf{R}$ given, 2.10 and $A = \frac{80bit}{0.32ms}$ is a normalization constant to convert to bps. The throughput corresponds to the defined as the ratio between the number of packets(bps) correctly delivered at the coordinator and the number of packet sent by the sensor nodes(RFDs).

Average power consumption:

The average energy consumption approximately is,

Operation mode	Power consumption
P_i	0.657 mW
P_{sc}	35.46 mW
P_t	31.32 mW
P_r	35.46 mW

Table 2.2: Power consumption of different operation modes

$$\begin{aligned}\tilde{E}_{tot} = \frac{P_i\tau}{2}\left(\frac{(1-x)(1-(2x)^{m+1})}{(1-2x)(1-x^{m+1})}W_0 - 1\right) + P_{sc}(2-\alpha)\tau + (1-\alpha)(1-\beta)\tau \\ \times (P_tL + P_i + L_{ack}(P_r(1-P_c) + P_iP_c)),\end{aligned} \tag{2.18}$$

where,P_i,P_{sc},P_t,P_r and P_{sp} are the average energy consumption in idle-listen, channel sensing, transmit, receiving, and sleep states, respectively, and quntity of them given at Table.2.2 [14].here, we assume the $P_{sp} \approx 0$ and P_c given at 2.3 [10],[18],[15].

2.4 A summary of data fusion theory

Data fusion(DF) or Multi Sensor Data fusion(MSDF) is a one of the magnificent fields related to expert and smart systems.A comprehensive definition of DF or MSDF which comprising all approaches coming in [31] as Data fusion (DF) or multi sensor data fusion (MSDF) is the process of combining or integrating measured or preprocessed data or information originating from different active or passive sensors or sources to produce a more specific, comprehensive, and unified dataset or world model about an entity or event of interest that has been observed. Due to vast area just be adequate to represent headline of DF issues here.For more excellent information referring to [31].A conceptual DF process is simply shown at Figure.2.9

2.4.1 Models of the Data Fusion Process and Architectures

Sensor-network fusion are assembled into various topologies and architecture based on type of application and sensor configuration as below,

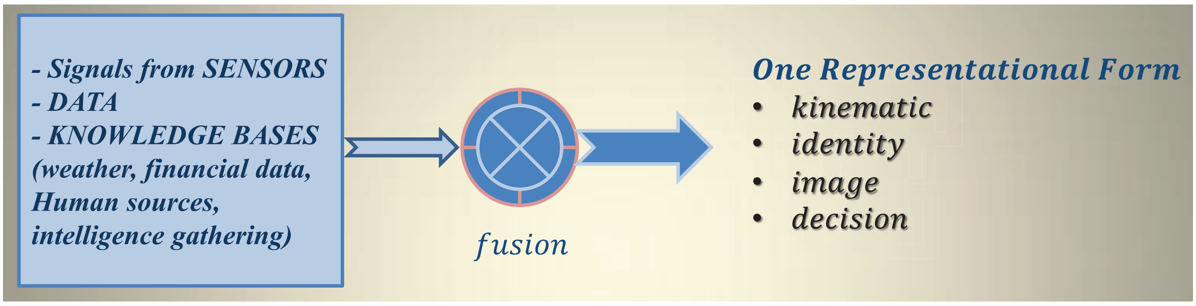

Figure 2.9: The conceptual chain of data fusion process from data to the fusion result

- Complementary type:configuration of sensors are independent from each other but every sensor observes one part of a region or phenomena and in group sensors then they can be combined results to given us completed picture of the phenomenon being observed.

- Competitive type:configuration of sensors are independent but each sensor delivers independent measurements of the similar feature or attribute.in this type numbers of sensors observed a phenomena.This confi guration would provide robustness and fault-tolerance because comparison with another competitive sensor can be used to detect faults.

- Cooperative type:configuration of sensors are in cooperative to each other,data provided by two and more sensors.cooperative sensor fusion is difficult to design, results of fusing data will be sensitive to the inaccuracies in all the individual sensors.

Three mentioned categories are not mutually exclusive more than one of the three types of configurations can be used in most cases. That is called hybrid configuration.

Data Fusion Models

MSDF is consist of number various task interconnects the various a and aspects and activities a synergy of sensing, signal and data processing, estimation, control, and decision making, data fusion models as followed [31]:

1. Joint Directors of Laboratories Model
2. Modified Waterfall Fusion Model
3. Intelligence CycleBased Model
4. Boyd Model
5. Omnibus Model

Fusion Architectures

Generally,arrangement of sensors for data acquisition adjust in three special architectures as below,

- Centralized Fusion
- Distributed Fusion
- Hybrid Fusion

Figure.2.10 represents different types of architectures.

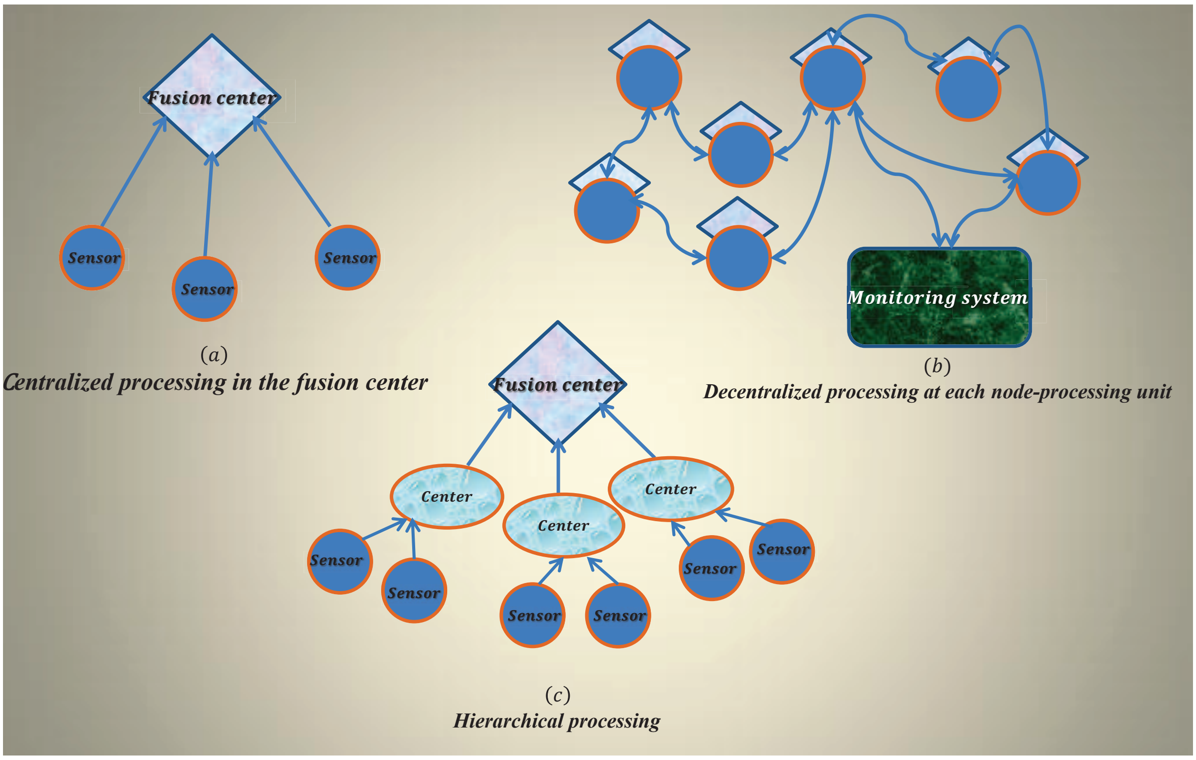

Figure 2.10: Three sensor data-fusion architectures

2.4.2 Unified Fusion Methodology

Actual data fusion method derived information or inference could be 1) probabilistic and statistical meyhods (e.g. Bayesian,...) 2) Estimation least-square (LS) and mean square methods (e.g.Kalman filter,...) 3) Other heuristic methods (e.g. ANNs, fuzzy logic,...)[31]. One of general fusion method with intergartion with decesion making is unified method with assuming:

$$z_i = h_i x + \eta_i,$$

z_i is the measurement of the ith sensor.
η_i is the measurement noise.
x local estimate is viewed as an observation with regarding to additive noise and weighted by h_i.The $z_i$linely process is sent to fusion center decision making.This model is referred to as the linearly processe data model for distributed fusion [31].

2.4.3 Theory of Fuzzy Logic

Comprehensive diagram for fuzzy implication process is came at [31] and shown in Figure, 2.11.

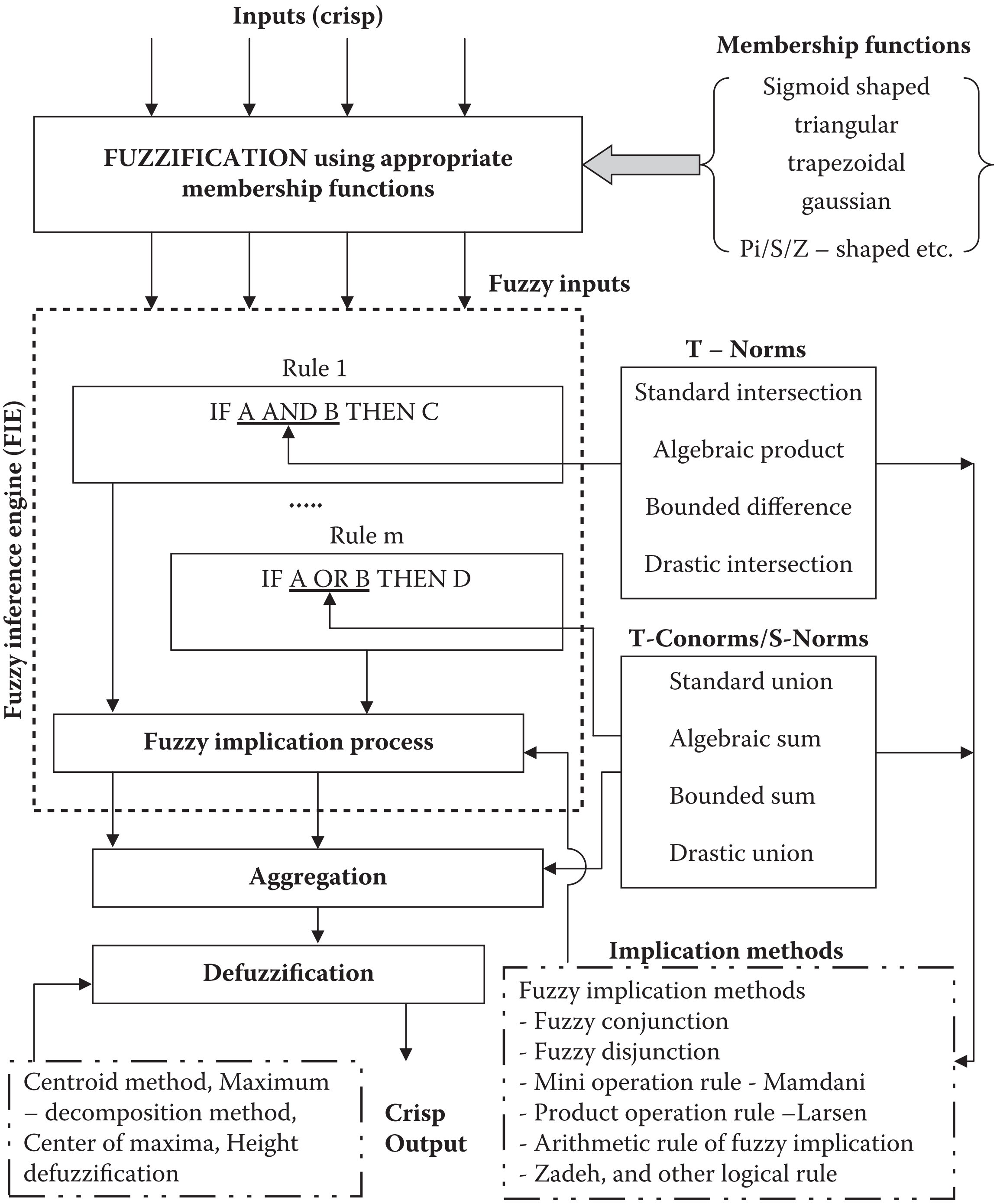

Figure 2.11: Comprehensive fuzzy implication process

Chapter 3

Performance Evaluation Framework

In this chapter, we will describe the analytical framework to evaluate performance metric. we investigate the problem decentralized distribution detection particularly when the sensor nodes detect a constant binary phenomenon .Sensing data packaged and forwarded to Access point(AP) through intermediate fusion center(FC) .Decision making fusion rule perform at FC with majority like signal power level reception compare to a threshold. Two ideal and noisy(non-ideal) channels assume and channel state information (CSI) considered with their impacts on fusion decision rule. Error Probability of decision measure at FC versus signal to noise ratio and modulation and coding. Moreover ,FC corresponding a FFDs according to IEEE 802.15.4 whereas sensor nodes are RFDs. Tree- based topology suppose with uniform and non-uniform nodes distribution per clusters. Chapter organized as follow.Section 2.1 illustrates the sensing model isotropic signal source for phenomenon of interest (PoI).In section 2.2 represents the architecture of parallel fusion with ideal channel and Adaptive White Gaussian Noise channel without clustering.section 2.3 presents the clustering model base on model section 2.1 ,2.2 ,analytical mathematical model for clustering would be present. Section 2.4 demonstrates performance metric equations based on Markov model which defined at sec 1.1. with new approach.

3.1 The Sensing Model

According to the stochastic geometry of sensing model, a Poisson Point Process (PPP) is characterized by nodes uniformly distributed with density of enviroment ρ. Sensing model is a isotropic signal source model for detecting phenomena of interest(PoI) with path loss factor α depend on distance of sensor from PoI and type of signal considered (chemical contamination, sound, radioactive radiation, etc)[32].Here, we assumed α is equal 1 and sensor distance from POI is $d = 1$.Thus,the received signal strength at a distance d away from the PoI is given by

$$S(d) = S_0/d^{\alpha} \tag{3.1}$$

$$\mathbb{P}\{N_t = n_t\} = \frac{\lambda_t^{n_t} exp(-\lambda_t)}{n_t!}, n_t \geq 0, \tag{3.2}$$

where, N_t is a Poisson r.v. with mean $\lambda_t = \mathbb{E}\{N_t\} = \rho.|A|$ where A is given a finite region of phenomenon.

we suppose the nodes sensing priodically independent condition on the whether PoI is absent or present.Particularly,while the PoI is present ,observations are not similar between nodes.Observations at sensor nodes are differnet.appropriated sampling and processing PoI for each node is,

$$y_n = \begin{cases} z_n, & \text{when PoI is absent,} \\ \sqrt{S(d_n)} + z_n, & \text{when PoI is present,} \end{cases} \tag{3.3}$$

where $n = 1, 2, .., N_t, z_n$ is the indepentend observation Gaussian distribution noise with zero-mean with variance σ_z^2 that, $N(0, \sigma_z^2)$,and $S(d_n)$ is the received signal strength at the nth node with a distance d_n far from the PoI given by 3.1Thus,we consider a sensor network observed a commone binary phenomenon whose the mentioned decentralized detection problem status defined as follows:

$$H = \begin{cases} H_0 : & \text{absent PoI with probability } p_0, \\ H_1 : & \text{present PoI with probabilty } 1 - p_0, \end{cases} \tag{3.4}$$

Information is gathered from observers of PoI ,located in center region A (enviroment of observed PoI), hence,equal probabililty is assumed in term of present or absent PoI.where $p_0 = \mathbb{P}\{H = H_0\}$, being $\mathbb{P}\{.\}$ the probabilty of given event.

3.2 Distributed Detection in Parallel Fusion Arhcitecture

Sensor nodes are organized according to Parallel Fusion Architecture (PFA) that represents on Figure 3.1 [32]. Each sensor independently detected the event under observation and generated information and send to FC through an ideal communication link.

Information could be sequence of bits as symbol for present or absent PoI. With respect to equation 3.2 , 3.3 observation ,we assumed sensor send 1 bit unit information to FC for decision making.A basic equation drived for received sensor observation signal at the FC from the nth sensor node is given by:

$$r_n = c_E + w_n \tag{3.5}$$

where , $c_E = \sqrt{aE_b}u_n$ and w_n is channel noise modeled with Gaussian distribution with zero-mean with variance $N_0/2$ and for across the nodes is independent identical distribution(i.i.d).E_b

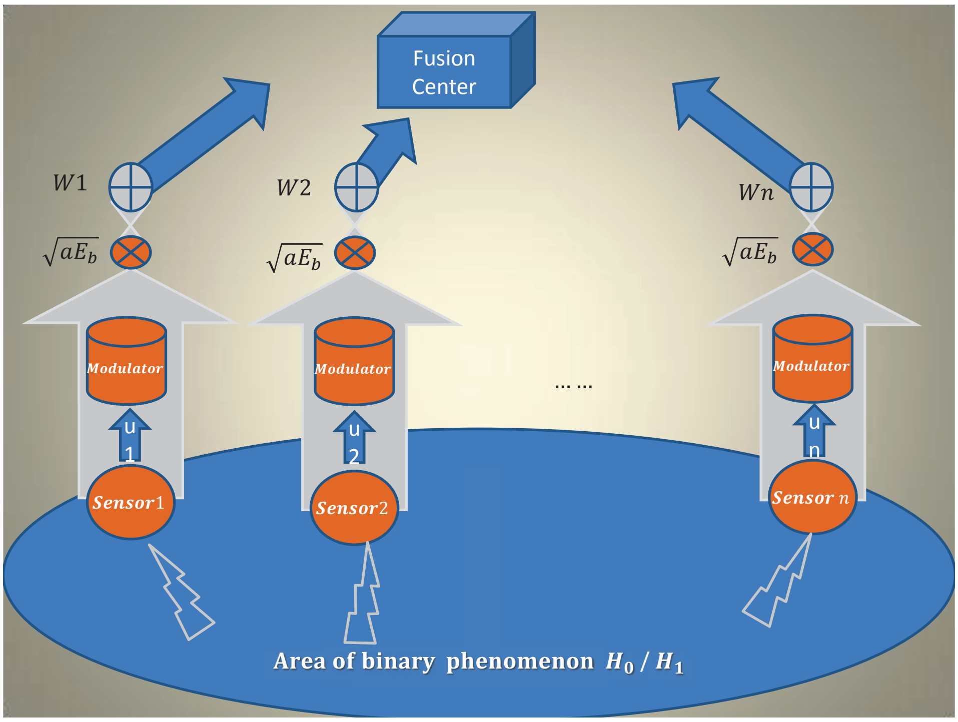

Figure 3.1: Parallel Fusion architecture

is the transmitted energy per bit and a is up-link path loss between sensor node and FC,respectively. Assuming a is identical for all nodes.The u_n is quantized local decision with two level of unit function for observation event coming as follow :

$$u_n = \begin{cases} +1 : & \text{when } \tilde{H}(y_n) = H_1, \\ -1 : & \text{when } \tilde{H}(y_n) = H_0, \end{cases} \tag{3.6}$$

The u_n assumed without loss statment in discrete-time ideal communication channel model.$\tilde{H}(y_n)$ is desicion making function at nth node. Now backing to sensing model, we are defined two probability flase-alarm and probability of detection correspondingly with performance detection of nth node. According to defination for detection at 3.3they remark with $P_f^{(n)}$, $P_d^{(n)}$, respectively[32].The probability false-alarm is given by:

$$P_f^{(n)} = \mathbb{P}\left\{y_n \geq \xi_n | H_0\right\} = Q\left(\frac{\xi_n}{\sigma_n}\right), \tag{3.7}$$

where, $Q(.)$ is Gaussian Q-function denotes: $Q(x) \triangleq \int_x^\infty \frac{1}{\sqrt{2\pi}} exp(-y^2/2)dy$.The $\xi_n$is the local signal desicion threshold at sensor nth within region PoI. the probability of detection at nth sensor node is also given by:

$$P_d^{(n)} = \mathbb{P}\left\{y_n \geq \xi_n | H_1, S(d_n)\right\} = P_d(\xi_n, d_n), \tag{3.8}$$

where $p_d(\xi, d)$ is defined by :

$$P_d(\xi, d) \triangleq Q\left(\frac{\xi - \sqrt{S_d}}{\sigma_z}\right). \tag{3.9}$$

We supposed the FC synchronize the whole nodes in the region A with sending a beacon periodically when FC wants to retrieve observation data.All nodes exactly triggered and send observing data to corresponding Fusion node at region A. With hypothesis ideal communication channels, decision made at FC base on Likelihood Raito Test (LRT) with level of received signal with comparison by a level of threshold signal denote by τ[1]. Threshold level could be adaptive and train during detection period in term of transmission signal power level[5][3].

3.2.1 Neyman-Pearson Hypothesis Testing

In this scenario is the need to make decision between two competing hypothesis. Here observing signal received to fusion node may is affected by many factors in an unforeseen manner, the decision making would be doing necessarily statistical. This formulates with a decision rule based on optimality criterion. Normally ,optimal criterion using three major methods are used , the Bayes risk criterion, the min-max criterion, and the Neyman-Pearson (NP) criterion. LRT is performed regrading to NP criterion[29].

3.2.2 Likelihood Raito Test (LRT)

Under NP criterion ,the optimal decision rule derived from a likelihood ratio test (LRT) choose based on the null and alternative hypotheses conditional probabilities[29].

$$\frac{\mathbb{P}\left\{\mathbf{r}|H_1\right\}}{\mathbb{P}\left\{\mathbf{r}|H_0\right\}} \overset{H_1}{\underset{H_0}{\substack{> \\ \leq}}} \tau \tag{3.10}$$

whereas,data vector $\mathbf{r}$ is given under the alternative as $\mathbb{P}\left\{\mathbf{r}|H_1\right\}$ and data vector $\mathbf{r}$ under the null hypothesis as $\mathbb{P}\left\{\mathbf{r}|H_0\right\}$.Decision would be making at fusion node based on receiving observed vector with taking the weighted u_n base on given[32] :

$$\sum_{n=1}^{N_t} u_n log\left[\frac{P_d^{(n)}(1-P_f^{(n)})}{P_f^{(n)}(1-P_d^{(n)})}\right] \overset{H_1}{\underset{H_0}{\substack{> \\ \leq}}} log\left[\frac{\mathbb{P}\left\{H_0\right\}}{\mathbb{P}\left\{H_1\right\}} \prod_{n=1}^{N_t} \frac{(1-P_f^{(n)})}{(1-P_d^{(n)})}\right] \tag{3.11}$$

where, $\mathbb{P}\left\{H_0\right\}$,$\mathbb{P}\left\{H_1\right\}$ are priori probabilities of the null and alternate hypothesis which are assumed to be known at the FC.we assumed the ideal communication channel.Alternatively,FC decision performs based on the N_t received observations of nodes. The vector $\mathbf{r}$ denoted gain of recieved signal in ideal Binary Symmetric Channels (BSCs) communication channel.This is corresponding N_t specified equation 3.5.Nevertheless,for simplicity the τ would be assumed

---

[1] The symbol τ was used in chp.2 for first probability of attempt for MAC,With a abuse of notation,it refers to threshold now,The context eliminates any ambiguity.

$\sqrt{snr}/2$ where $snr = aE_b/N_0$ is received signal to noise (SNR) from each sensor node through communication channel at fusion center[32].

$$\mathbf{r} = [r_1, \cdots, r_i]^T \tag{3.12}$$

$$i = (1, \cdots, N_t),$$

the optimal fusion rule represent respectively as follow:

$$\Delta(\mathbf{r}) = log \left[\prod_{n=1}^{n_t} \frac{P_{v_1}(V_1)}{P_{v_0}(V_0)} \right] \underset{H_0}{\overset{H_1}{\substack{> \\ \leq}}} \tau, \tag{3.13}$$

where, $P_{v_1}(V_1)$,$P_{v_0}(V_0)$ are probability density funstion (p.d.f) of conditional respectively on H_1,H_0 such as, $V_1 = r_n$—H_1 and $V_0 = r_n$—H_0.Assuming optimal fusion rule adopts the equal gain combining(EGC) fusion rule given by :

$$\Delta(\mathbf{r}) = \frac{1}{n_t} \sum_{n=1}^{n_t} r_n \underset{H_0}{\overset{H_1}{\substack{> \\ \leq}}} \tau, \tag{3.14}$$

The Bayesian approach is considered, whereby the a priori probabilities of the absent or present hypothesis PoI,$\mathbb{P}\{H_0\}$ and $\mathbb{P}\{H_1\}$ at fusion center. With employ the EGC fusion rule equation in 3.14 we have probability of decision error at fusion center base on detection of PoI as follow:

$$P_e = \mathbb{P}\left\{\hat{H} = H_1 | H_0\right\} \mathbb{P}\{H_0\} + \mathbb{P}\left\{\hat{H} = H_0 | H_1\right\} \mathbb{P}\{H_1\} \tag{3.15}$$

3.3 Distributed Detection in Clustered Sensor Networks

We are considered a network sensor where n sensors observe a common binary phenomenon whose status is defined at 3.4 where the $p_0 = \mathbb{P}\{H = H_0\}$, is $\mathbb{P}\{.\}$ the probability of given event. n sensors organized into the cluster groups $n_c < n$, sensor as a RFD just communicate with head of clusters whereas is a FFD with acting as Fusion center. First level FCs gather the data from sensors belong to corresponding clusters.All sensors for each cluster organized with PFA structure discribeing in Section 3.2.Figure3.2 shows clustring architecture[8].

According to equation 3.5 we rewrite c_E by:

$$c_E = \begin{cases} 0 & \text{if } H = H_0, \\ s & \text{if } H = H_1, \end{cases} \tag{3.16}$$

where w_n is noise samples are Guassian distribution $N(0, \sigma^2)$ and independent.the general SNR at sensors define[3] :

$$SNR_{sensor} = \frac{\left[\mathbb{E}\{c_E | H_1\} - \mathbb{E}\{c_E | H_0\}\right]^2}{\sigma^2} = \frac{s^2}{\sigma^2} \tag{3.17}$$

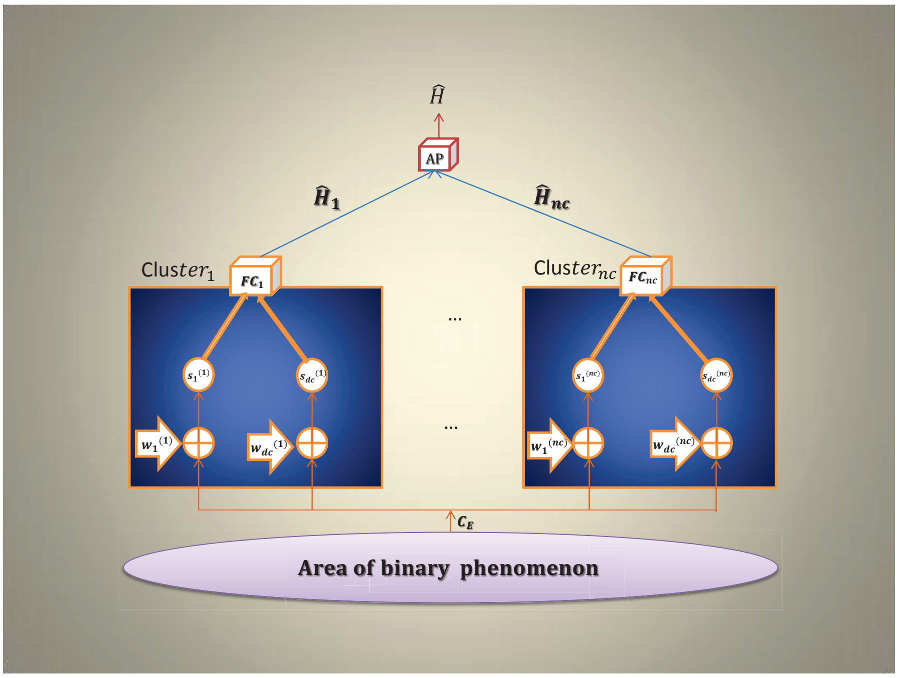

Figure 3.2: Block diagram of a clustered sensor network

As discussed in Section 3.2 Each sensor makes a decision comparing its observation with a threshold value ξ locally and then forward to FC as r_i and do decision with threshold τ.In ideal channel can use $\xi = \tau$ interchangeably.we assume sensor doing perfectly detection and fusion action only happens in fusion center. The senario distribution detection in cluster networks the sensors grouped into the clusters with uniform or non-uniform distributions topology.Initially,we assume the channel between the sensors and fusion center is ideal communcation like as a Binary Symmetric Channels (BSCs) with probability p cross-over, memoryless communication channels. But later our senario turn to wireless non-ideal channel with channel affects on data packets.

3.3.1 Uniform Clustering with ideal communcation link

Decision made at fusion node is performed with majority-like (some literature mentioned Consensus flooding or voting mechanism) received signal. Majority-like mechanism is attend to number of sensors in clusters.For first level of fusion if number of sensors contain d_c in uniform distribution clustering , n_c is number of clusters, where $n = d_c.n_c$ describe all sensors, then $k = [d_c/2] + 1$ is floor of majority-like in first level of fusion at a cluster. Second level decision making,for n_c clustering head (FC) perform at Access Point (AP) looklike a FC, in this step mechanism performs with at least $k_f = [n_c/2] + 1$ majority-likes.Figure3.3 represent a uniform clustering with $n = 12$ sensors $n_c = 3$,$d_c = 4$ for two level fusion[5].

According to uniform definition,th P_e ,indicated in 3.15 probability of error for uniform

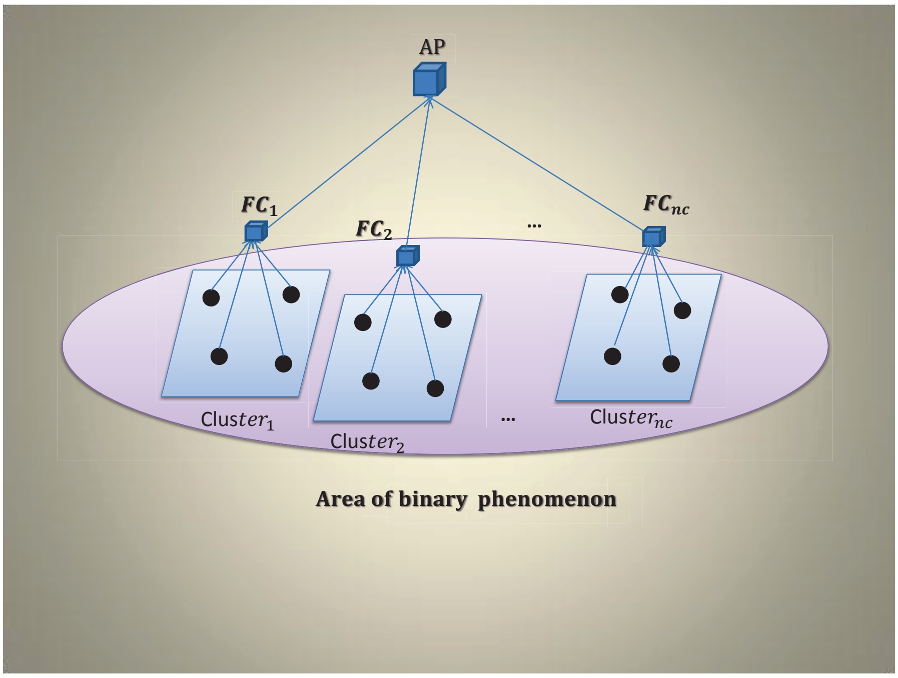

Figure 3.3: Uniform clustering with $n = 12$ sensors $n_c = 3$,$d_c = 4$.

distribution clustring merely for two level fusion(FC and AP)is deriven by [5]:

$$P_e = p_0 fbin\left(k_f, n_c, n_c, fbin\left(k, d_c, d_c, Q\left(\tau\right)\right)\right) + \tag{3.18}$$

$$\left(1 - p_0\right) fbin\left(0, k_f - 1, n_c, fbin\left(k, d_c, d_c, Q\left(\tau - s\right)\right)\right),$$

where, $Q\left(x\right) \triangleq \int_x^\infty \frac{1}{\sqrt{2\pi}} exp\left(-y^2/2\right) dy$ is error function and

$$fbin(a, b, n, z) \triangleq \sum_{i=a}^{b} \binom{n}{i} z^i \left(1 - z\right)^{(n-i)} \tag{3.19}$$

Also, $a, b, n \in \mathbb{N}$ and $z \in (0, 1)$.If $n_c = k_f = 1$ and $d_c = N$, there is no clustring and probability of decision error reduce to,

$$p_e = p_0 \sum_{i=0}^{k-1} \binom{N}{i} \left[1 - Q\left(\tau - s\right)\right]^i \left[Q\left(\tau - s\right)\right]^{N-i} + \left(1 - p_0\right) \sum_{i=k}^{N} \binom{N}{i} \left[1 - Q\left(\tau\right)\right]^i \left[Q\left(\tau\right)\right]^{N-i}, \tag{3.20}$$

Numerically,best fusion rule can represent with majority rule $k = \lfloor N/2 \rfloor + 1$, In order to large number of sensor nodes i.e. $N \gg 1$,We can use De Moivre-Laplace approximation to to evaluate the sums of binomial terms which appear in 3.20.Approximation p_e would be as follow:

$$p_e = p_0 Q\left(\frac{k-1-\eta_1}{\sigma_1}\right) + (1-p_0)\left[1 - Q\left(\frac{k-1-\eta_2}{\sigma_2}\right)\right] \tag{3.21}$$

$$\eta_1 \triangleq N\left[1 - Q\left(\tau - s\right)\right],$$

$$\sigma_1 \triangleq \sqrt{N\left[1 - Q\left(\tau - s\right)\right] Q\left(\tau - s\right)},$$

$$\eta_2 \triangleq N\left[1 - Q\left(\tau\right)\right],$$

$$\sigma_2 \triangleq \sqrt{N\left[1 - Q\left(\tau\right)\right] Q\left(\tau\right)}.$$

3.3.2 Non-uniform Clustering with Ideal Communcation Links

Non-uniform denotes distribution of sensors in clusters with unequal number of grouped sensors for each cluster[8][17].The probability of decision error in a generic scenario with non-uniform clustering can be evaluated as below ,initially, we define cluster size vector $D \triangleq \left\{d_c^{(1)}, d_c^{(2)}, \cdots, d_c^{(n_c)}\right\}$, where $d_c^{(i)}$ is the number sensors in the ith cluster $(i = 1, 2, ..., n_c)$ and $\sum_{i=1}^{n_c} d_c^{(i)} = N$,Moreover,Two vector remark as follow:

$$P^{1|1} \triangleq \left\{p_1^{1|1}, p_2^{1|1}, \cdots, p_{n_c}^{1|1}\right\}$$

$$P^{1|0} \triangleq \left\{p_1^{1|0}, p_2^{1|0}, \cdots, p_{n_c}^{1|0}\right\}$$

represent the $P^{1|1}$ probability of success and $P^{1|0}$probability of failure decides at FC ,respectively[15].then,probability of error coming as folow:

$$P_e = p_0 \sum_{i=k_f}^{n_c} \sum_{j=1}^{\binom{n_c}{i}} \prod_{\ell=1}^{n_c} \left\{c_{i,j}\left(\ell\right) p_\ell^{1|0} + \left(1 - c_{i,j}(\ell)\right)\left(1 - p_\ell^{1|0}\right)\right\} \tag{3.22}$$

$$+ (1-p_0) \sum_{i=0}^{k_f-1} \sum_{j=1}^{\binom{n}{i}} \prod_{\ell=1}^{n_c} \left\{c_{i,j}\left(\ell\right) p_\ell^{1|1} + \left(1 - c_{i,j}(\ell)\right)\left(1 - p_\ell^{1|1}\right)\right\}$$

where $\mathbf{c}_{i,j} = (c_{i,j}(1), \cdots, c_{i,j}(n_c))$ is vector which designates the jth configuration of the decision from first-level fusion node in a case with i, $1s$ and $n_c - i$, $0s$.On the other words,$c_{i,j}$ can represent by $string(i,j,\ell) = 1$ if there is a **success**,corresponding to a decision, at ℓth FC or AP, in favor of H_1,whereas it is 0 if there is a **failure**,corresponding to a decision, at ℓ FC or AP in favor of H_0.for $string(i,j,\ell)$ could be an auxiliary binary function used to distinguish, in the repeated trials formula, between a success and a failure[8].for example, possible configuration for $n_c = 4$ clusters illustrate in Table 3.1.

i	j	$\mathbf{C}_{i,j}$
0	1	0000
1	1	1000
	2	0100
	3	0010
	4	0001
2	1	1100
	2	1010
	3	1001
	4	0101
	5	0110
	6	0011
3	1	1110
	2	1011
	3	0111
	4	1101
4	1	1111

Table 3.1: Possible configuration for $n_c = 4$ clusters

3.3.3 Clustring senario with Noisy Communication Links

In pervious section represent the P_e probability of decision error can be derived with 3.22 .If probabilities $\left\{p_\ell^{1|i}\right\}_{\ell=1,\cdots,n_c}^{i=0,1}$ replacing by $\left\{p_{\ell,noisy}^{1|i}\right\}_{\ell=1,\cdots,n_c}^{i=0,1}$, which cover noisy effect at communication links between sensors and FCs, probability of decision error at FC would be :

$$P_e = p_0 \sum_{i=k_f}^{n_c} \sum_{j=1}^{\binom{n}{i}} \prod_{\ell=1}^{n_c} \left\{ c_{i,j}\left(\ell\right) p_{\ell,noisy}^{1|0} + \left(1 - c_{i,j}(\ell)\right) \left(1 - p_{\ell,noisy}^{1|0}\right) \right\} \tag{3.23}$$

$$+ \left(1 - p_0\right) \sum_{i=0}^{k_f - 1} \sum_{j=1}^{\binom{n}{i}} \prod_{\ell=1}^{n_c} \left\{ c_{i,j}\left(\ell\right) p_{\ell,noisy}^{1|1} + \left(1 - c_{i,j}(\ell)\right) \left(1 - p_{\ell,noisy}^{1|1}\right) \right\}$$

where, $p_{\ell,noisy}^{1|0}\left(d_c^{(\ell)}\right) = \sum_{m=k_\ell}^{d_c^{(\ell)}} \binom{d_c^{(\ell)}}{m} p_{10}^m p_{00}^{d_c^{(\ell)}-m}$, also, $p_{\ell,noisy}^{1|1}\left(d_c^{(\ell)}\right) = \sum_{m=k_\ell}^{d_c^{(\ell)}} \binom{d_c^{(\ell)}}{m} p_{11}^m p_{10}^{d_c^{(\ell)}-m}$. here ,$k_\ell$ depends on number of packets received at the ℓth FC.for decision at AP with same favor of FC for k_f still can apply for value of k_ℓ. Obviously,p_{10} is probability that a sensor decision sent to an FC is in fovar of H_1 when H_0 has happened and can be represent $p_{10} = 1 - p_{00}$ equal by,

$$P_{10} = Q(\tau)(1 - p) + [1 - Q(\tau)]p \tag{3.24}$$

Since,the first term of right-hand side present when ideal channel link exist with sensor observation error whearas, the second term when non-ideal communication link exist without sensor observation error.with the same senario, $P_{11} = 1 - P_{01}$ represents the probability that a decision sent by a sensor to an FC is in favor of H_1, when H_1 has happened and can be given the following expression[17]:

$$P_{11} = Q(\tau - s)(1 - p) + [1 - Q(\tau - s)]p \tag{3.25}$$

Merging equations 3.7 , 3.9 with 3.24 , 3.25 then,

$$P_{10} = Q\left(\frac{\xi_n}{\sigma_n}\right)(1 - p) + [1 - Q\left(\frac{\xi_n}{\sigma_n}\right)]p = P_f^{(n)}(1 - p) + (1 - P_f^{(n)})p, \tag{3.26}$$

Also,

$$P_{11} = Q\left(\frac{\xi - \sqrt{S_d}}{\sigma_z}\right)(1 - p) + [1 - Q\left(\frac{\xi - \sqrt{S_d}}{\sigma_z}\right)]p = P_d^{(n)}(1 - p) + (1 - P_d^{(n)})p. \tag{3.27}$$

3.4 Communication Channel State Information Scheme

In this section, channel rules would be explained in interplaying with decision making at fusion. Generated packet bits sequentially,bit to bit sent to fusion node through a communication channel. The impact of channel condition or channel state information (CSI) is significant on decision at fusion node. In addition to sensor observation quality, Probability of error (P_e) at FC completely related to channel condition and Received Signal Strength Indication(RSSI) power bits.Therefore, we will expand our design with assuming an CSI probability of channel which remark P_{csi}. Here we considered a senor network model with no interference impact (Orthogonal transmission) because of exact scheduling between the sensors and Fusion node or AP by way of beacon transmission periodically from FC or AP to sensor nodes when sampling of POI happens.

3.4.1 The Rayleigh fading affect

In this subsection we would be expressed using a statistical model for the affect of a propagation environment on a radio signal.The fading affect is attenuated the signal in propagation medium.The fading fluctuates in time, radio frequency or environment position and modeled as a random process.Due to position of transmitter versus receiver regarding to be line- of-side (LOS) or non LOS, the multipath fading models by Rice and Rayleigh distribution respectively.The Rayleigh distribution is frequently used to model multipath fading with no direct line-of-sight (LOS) path[17]. the equation 3.5 with Rayleigh fading given by:

$$r_i = f_i(2c_i - 1)\sqrt{E_c} + w_i, \tag{3.28}$$

$$i = 1, \cdots, N + L$$

Where, f_i is a random variable with Rayleigh distribution with perfectly coherent demodulation consideration:

$$f(x;\sigma) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2}, x \geq 0,$$

And also,$c_i \in \{0,1\}$ is indicated symbol transmitted from either a sensor in a (repetition or block) coded scenario with Binary Phase Shift Keying(BPSK).The $E_c$is the energy per coded bit whereas $E_c \triangleq R_c E_b$.the E_b denotes the energy per information bit and $R_c = 1/M$ being code rate that interpreted as a system embedding a repetition code at each sensor when the M is consecutive and independent observations of the same phenomenon at a sensor network with multiple observations[17].for example,in a systematic block channel code with hypothesising that each sensor makes a single observation,a raly by using Hamming systematic block code, generates parity bits and sends them to the Fc or AP.for $N = k = 4$ observer sensors and one relay,generates $L = n - k = 3$ bits according to the parity-check equations then remarks $(n,k) = (7,4)$ systematic Hamming code.In a single transmission act, the total number of transmission acts in the proposed sensor network is $N + L$. The R_c computesin this distributed coded scheme $R_c = N/(N+L) = 7/4$.

Now,Bit Error Rate (BER) with BPSK or QPSK modulation at fusion node for Rayleigh fading channel given by:

$$p^{Rayleigh} = \frac{1}{2}\left[1 - \sqrt{\frac{R_c\gamma_b}{1 + R_c\gamma_b}}\right] \tag{3.29}$$

$\gamma_b \triangleq E_b/N_0$ is SNR received at Fusion node or AP.

3.4.2 Impct of Channel Dynamics

The extent of probability channel state (P_{csi}) for link quality is a desired abstraction for bit reception rate,on the other view,packet reception rate, as a function of distance.this abestraction con be derived by by composing the channel model,which provides the received signal strength (RSS) as function of distance with radio-receiver model that can be as a fusion center or access point which given by a function signal-to-noise ratio (SNR).nevertheless,channel stste analysis with respect to a unreliabilty and asymmetry in low-power wirless link.

Pathloss effects

According to channel model between sensor and transmitter and receiver and FC or AP ,the received power P_r in dB is as follow:

$$P_r(d) = P_t - PL(d_0) - 10\,\eta\, log_{10}\left(\frac{d}{d_0}\right) + N(0,\sigma), \tag{3.30}$$

$$PL(d_0) = 20 * log_{10}(f)$$

where, P_t is the output power, η is the pathloss exponent Which takes the rate of signal attenuation based on distance obtian empirical measurment[9,24]. Table.3.2 shown some

Parameter η	Environment
2.0	Free space
1.6 to 1.8	Inside a building, line of sight
1.8	Grocery store
1.8	Paper/cereal factory building
2.09	A typical $15m \times 7.6m$ conference room with table and chairs
2.2	Retail store
2 to 3	Inside a factory, no line of sight
2.8	Indoor residential
2.7 to 4.3	Inside a typical office building, no line of sight

Table 3.2: Path-loss Exponent (η) for Different Environments

measurment. $N(0, \sigma)$ is a Gaussian random variable with mean 0 and variance σ (standard deviation due to multipath shadowing effects). $PL(d_0)$ is power attenuation at source with distance d_0 at frequency $f = \frac{v}{\lambda}$ which v is velocity light,λ is wavelength.equation 3.30 is a consider in a isotropic transmission,which is one significant specification of low-power wireless link.

Fusion Center Radio Receiver

In the receiver,here is FC, responsonse is defined by packet reception rate as a function of the SNR.The packet reception rate can be obtianed from using bit error rate expressions[9].regarding to differing in modulation with $Symbolperbit = log_2 M$ data bits, the packet-reception rate (Ψ) is defined in terms of the bit-error rate (β_M) that given by :

$$\Psi(\gamma) = 1 - (\beta_M(\gamma))^b, \tag{3.31}$$

where b is number of bits transmitted and β_M represents based on Modulation scheme at Table3.3 And also,we know β_M is a function of the SNR.therefor,obtianing SNR in $dB(\gamma_{dB})$ as a function of distance is:

$$\gamma(d) = P_r(d) - P_n \tag{3.32}$$

Where the $P_r(d)$ is expression at 3.30.The P_n is noise floor[2] with constant amount at 15° a normal degree Celcius[9].

$$\gamma_{dB}(d) = P_t - PL(d_0) - 10\,\eta\, log_{10}(\frac{d}{d_0}) - N(0, \sigma) - P_n \tag{3.33}$$

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[2] Becuase of interference-free enviroment in these scenarios, P_n is given only by a constant thermal noise, which in turn leads to constant packet reception rates in time.it computes based on $P_n = 10\, log_{10}(bol * T * B * 10^3) + noisefigure + 1$ where,bol = Boltzmann constant and T is Temperature(kelvien) and B is bandwidth in Hz. Nevertheless, in most scenarios P_n changes with time, either because of interference or because of large changes in temperature.For such scenarios P_n can be modeled as a stochastic random process.

Modulation	Bit Error Rate β_M
ASK noncoherent	$\frac{1}{2}[exp^{-\frac{\gamma(d)}{2}\frac{B_N}{R}} + Q(\sqrt{\gamma(d)\frac{B_N}{R}})]$
ASK coherent	$Q(\sqrt{\frac{\gamma(d)}{2}\frac{B_N}{R}})$
FSK noncoherent	$\frac{1}{2}\ exp^{-\frac{\gamma(d)}{2}\frac{B_N}{R}}$
FSK coherent	$Q(\sqrt{\gamma(d)\frac{B_N}{R}})$
PSK Binary	$Q(\sqrt{2\ \gamma(d)\frac{B_N}{R}})$
PSK differential	$\frac{1}{2}exp^{-\gamma(d)\frac{B_N}{R}}$
	here,γ_d is not in dB then $\gamma_d = 10^{\frac{\gamma_{dB}}{10}}$ from 3.36
	B_N is noise bandwith and R is bit data rate.

Table 3.3: BER β_M for different Modulations

From given expression 3.32 ,3.33 the SNR is in dB ,however, denoting $\omega(x) = 10^{x/10}$ the bit-error rate for SNR in dB is rewritten :

$$\Psi(\gamma_{dB}) = (1 - \beta_M(\omega(\gamma_{db})))^b \tag{3.34}$$

3.4.3 Impact of radio tarnsmitter variance

So far,it was assumed the all radios transmitting with the similar output power P_t and noise floor P_n,however,radio transmitter variance causes some fluctuation around power output and and average noisefloor.for example ,user power sets or using different manufactural kind of radio for inducing power output variance and differing enviromental affect for noisefloor should be taken into the account.based on a empirical measurment within a radio ,output power and noise floor are correlated.with representing the output power and noise floor as multivariate Gaussian distribution [3] as given by [9 ,34]:

$$\begin{pmatrix} T \\ R \end{pmatrix} \approx N\left(\begin{pmatrix} P_t \\ P_n \end{pmatrix}, \begin{pmatrix} S_T & S_{TR} \\ S_{RT} & S_R \end{pmatrix}\right), \tag{3.35}$$

where,P_t is the output power and P_n is the average noise floor.S the covariance matrix between the output power and noise floor, and T and R the actual output power and noise floor of a specific radio, respectively. Therefor, $\gamma_{dB}(d)$ can be given by :

$$\gamma_{dB}(d) = T - PL(d_0) - 10\ \eta\ log_{10}(\frac{d}{d_0}) - N(0, \sigma) - R \tag{3.36}$$

In the senario also channel encoding is considered , achieved packet reception rate in term

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[3] we assume S = [6.0 -3.3,-3.3 3.7] according to [9]

Encoding Scheme	Channel State Probability P_{csi}
NRZ(Non-Return zero)	$(1-p_b)^{8\ell}(1-p_b)^{8(b-\ell)}$
4B5B	$(1-p_b)^{8\ell}(1-p_b)^{8(b-\ell)1.25}$
Manchester	$(1-p_b)^{8\ell}(1-p_b)^{8(b-\ell)2.0}$
SECDED	$(1-p_b)^{8\ell}((1-p_b)^8+8p_b(1-p_b)^7)^{(b-\ell)3.0}$
	p_b obtian $10^{(\gamma_{dB}(d)/10)} \implies$ RSSI $\implies$ Table3.3.
	here,ℓ is Preamble length where,b is frame length.

Table 3.4: Probability of Channel Encoding Scheme

on bits rate obtians with appropriated modulation.Desired BERs are shown in Table3.3 and denoted by p_b in channel encoding table.Channel encoding could be obtianed from Table3.4 [9].

By using and replacing $\gamma_b(d) = \omega(\gamma_{dB}(d))$ into the expression $p^{Rayleigh}$ given at 3.29 is BER output communication link at fusion node or AP based on falt-fading channel and pathloss effect with noise as impct of channel dynamic [9,19] .With some manipulation channel state probability explains for BPSK and QPSK modulation as:

$$P_{csi}^{Rayleigh} = \frac{1}{2}\left[1 - \sqrt{\frac{R_c\gamma_b(d)}{1+R_c\gamma_b(d)}}\right] \tag{3.37}$$

Obviously, BER expression can be expalin based on differant distance and modulation as well as fading .The obtinaing $P_{csi}^{Rayleigh}$ probabitiy of noisy channel substitute for p in 3.23 as communication channel state quality then for clustring decentrized distribute detecton P_e at Fusion or AP is given:

$$P_e = p_0 \sum_{i=k_f}^{n_c} \sum_{j=1}^{\binom{n}{i}} \prod_{\ell=1}^{n_c} \left\{ c_{i,j}(\ell)\, p_{\ell,csi}^{1|0,Rayleigh} + (1-c_{i,j}(\ell)) \left(1 - p_{\ell,csi}^{1|0,Rayleigh}\right) \right\} \tag{3.38}$$

$$+ (1-p_0) \sum_{i=0}^{k_f-1} \sum_{j=1}^{\binom{n}{i}} \prod_{\ell=1}^{n_c} \left\{ c_{i,j}(\ell)\, p_{\ell,csi}^{1|1,Rayleigh} + (1-c_{i,j}(\ell)) \left(1 - p_{\ell,csi}^{1|1,Rayleigh}\right) \right\}$$

3.5 Meduim Access Control role on decentralized detection scheme

This section represents a framework for computation the probability of decision error in existence of IEEE 802.15.4 MAC affects.Several literatures investigated impact of MAC on decision error with number of sensors in the cluster as a contention-based state protocol which causes the collision.In our framework brings the channel channel state take into the account that charactrized in previous section.Markov chain and performance metric expression also consider with information fusion and clustring on distributed detection approaches.While the the Markov chain just declared the probability of collisionP_c in experssion 2.3 as cause of loss,we bring P_{csi} ,which derived in pervious subsection Table.3.4,into the account as another possibility of loss due to different SNR with Modulation and coding.hence,Markov chain updating with new term that cover collision and different SNR with Modulation and channel coding impact togather with following equation,

$$P_{fail} = 1 - (1 - P_c)(1 - P_{csi}), \tag{3.39}$$

where,P_c is given 2.3.In all expression by P_c term,replace by P_{fail} afterward. With assuming the independent jth clusters transmission could be modeling with binominal random variable, remarked $D_c^{(j)}$ where $(j = 1, \cdots, n_c)$, the $d_c^{(j)}$ is referring to cluster size,denote a probability $p_{mac}(d_c^{(j)})$ corresponding to jth cluster .with this inspiration , can compute any probability with respect to fusion-based and clustering topology.that is:

$$P(\Im) = \sum_{i_1=0}^{d_c^{(1)}} \sum_{i_2=0}^{d_c^{(2)}} \cdots \sum_{i_{n_c}=0}^{d_c^{(n_c)}} \mathbb{P}\left\{D^{(1)} = i_1\right\} \cdot \mathbb{P}\left\{D^{(2)} = i_2\right\} \cdots \mathbb{P}\left\{D^{(n_c)} = i_{n_c}\right\} \tag{3.40}$$

where, $\Im$ denotes possible variable which could compute,and also,

$$\mathbb{P}\left\{D^{(\ell)} = i_\ell\right\} = \binom{d_c^{(\ell)}}{i_\ell} \left[p_{mac}(d_c^{(\ell)})\right]^{i_\ell} \left[1 - p_{mac}(d_c^{(\ell)})\right]^{d_c^{(\ell)} - i_\ell} \tag{3.41}$$

Now,using Markov chain performance metric equations,

Reliability:

The probability of successful delivery of packets **R** as a clustring topology network,regarding to 2.10 , 3.41 and 3.40 redefines the probability of successful delivery of packets majority sensors per cluster which satisfy majority-like fusion strategy,is:

$$P_R^{i_\ell} = \sum_{i_\ell=\chi}^{d_c^{(\ell)}} \prod_{\ell=1}^{n_c} \binom{d_c^{(\ell)}}{i_\ell} \left[\mathbf{R}(d_c^{(\ell)})\right]^{i_\ell} \left[1 - \mathbf{R}(d_c^{(\ell)})\right]^{d_c^{(\ell)} - i_\ell} \tag{3.42}$$

where $\chi = \left\lfloor d_c^{(\ell)}/2 \right\rfloor + 1$, $\ell = \{1, \cdots, n_c\}$,Supposing two levels fusion at FC and AP,$P_R^{i_\ell}$ is given the probability of successful delivery distributed sensors in first level fusion ,now The probability of successful delivery FC to AP has similarty by assuming as a cluster with n_c sensors for second level fusion.hence,with using the equation in term of between FC and AP,$\mathbf{R}_c$ is,

$$\mathbf{R}_c = P_R^{i_\ell} \cdot P_R^{(fc)}, \tag{3.43}$$

where ,$P_R^{(fc)}$ obtianing from 3.41 and 3.40 just once computation with $d_c^{(fc)} = n_c$.

Average delay:

The average delay for clustering with two level fusion is defined a average delay of successfully received packet as the time interval from the instant the packet is at the head of its MAC queue and ready to be transmitted, until the transmission is successful and the ACK is received from both level of fusion nodes,respectively.According to given expression 2.13 to 2.16,bring those to framework except the constants(fram length,Ack length,$\cdots$),MAC parameters only two terms ,$Pr(A_j|A_t)$ and$\tilde{P}(B_i|B_t)$ could be computed based on 3.40 and 3.41.therefor,initially α,β,τ should be calculate with respect to given topology at clusters then x,y and P_c(with term 3.39).Obviously,MAC parametrs are similar for all equations.with concerning to framework senario number of majority-like sensors should be taken into account when encounter with N number sensor in orginal Markov chain equations that replacing by $\lfloor d_c/2 \rfloor + 1, \cdots, d_c$ for each cluster with product by corresponding sensors.So far,average delay computes for first level fusion for each cluster separately.for second fusion level also acting as a cluster with n_c sensors.Now, for average delay whole network :

$$\mathbb{E}_c^{(av)}[\tilde{D}] = \frac{Max\left\{\mathbb{E}_c^{(1)}[\tilde{D}], \cdots, \mathbb{E}_c^{(n_c)}[\tilde{D}]\right\} + Min\left\{\mathbb{E}_c^{(1)}[\tilde{D}], \cdots, \mathbb{E}_c^{(n_c)}[\tilde{D}]\right\}}{2} + \mathbb{E}^{(fc)}[D], \tag{3.44}$$

first term is average delay which packets arriving for first level fusion at FC clusters head and second term for which packets arriving second level fusion at AP.Becuase of synchronized network ,transmission happens same time and concurrently,hence,*Max* and *Min* compute regardig to cluster size and parameters.

Network aggregate throughput:

Network aggregate throughput for minimum effective number of nodes for each cluster network with two level fusion is given by:

$$S_c = g \cdot A \cdot L_s \cdot \hbar \cdot \mathbf{R}_c \tag{3.45}$$

where the $\hbar = \sum_{\ell=1}^{n_c} \left\lfloor d_c^{(\ell)}/2 \right\rfloor + 1$.

Average power consumption:

The average power consumption computes into the clustering framework with two levels fusion,using equation 2.18 with similar approach described for average delay. constant value are given in Table.2.2 are using for first level fusion,however,for second level fusion are valid

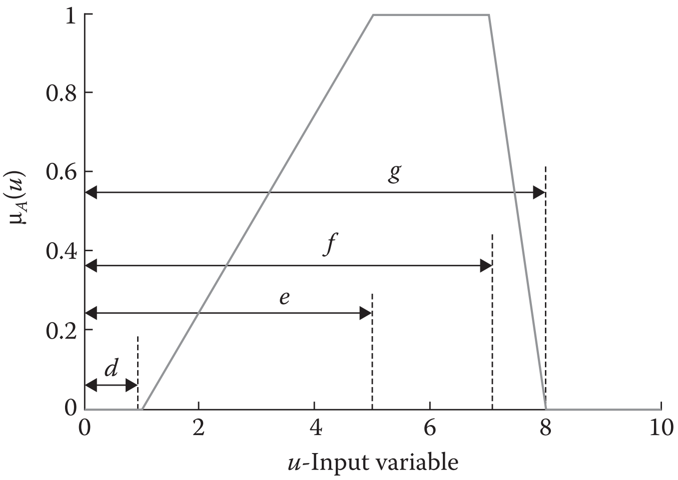

Figure 3.4: Trapezoid-shaped membership function

except assumed $P_i \approx 0$ becuase of assuming fusion center does not have ideal state at second level,also hypothesis P_{sc} sensing power constant at sensor is corresponding with power of decision making at fusion node and assumed same compuatation term.

3.6 Fuzzy logic fusion for a coverage inquiry

In this part of project with other point of view, fuzzy logic fusion used for coverage wireless sensor network or inquiry of quality received signal bits to coordinator or fusion node. So far, assuming the maximum and minimum distance for between the sensors and FC .Basically, in real situation sensors located in different distance from FC even inside of same cluster. Now, we will show received signal strength in fusion center as calls coverage or percentage of coverage network. Therefor, two input parameters are defined as distance between sensors and FC and signal to noise ratio (SNR) of channel. Received Signal Strength Indication (RSSI) equation is shown in 3.30 ,if results of equation 3.30 calls $RSSI_d$,snr in term of $RSSI_d$ is:

$$E_b/N_0 = 10^{(RSSI_d - Noise)/10} \tag{3.46}$$

where,noise is $N(0, \sigma)$.Implementation fuzzy should be using the membership functions for input and output a fuzzy process.Trapeziod-shaped membership function with corresponding experssion are shown figures,3.4 and 3.5 [31]. Another membership function of fuzzy logic is Gaussian-Shaped Function is represented in Figure,3.6 and coressponding experssion is [31]:

$$\mu_A(u) = e^{\frac{-(u-a)^2}{2b^2}} \tag{3.47}$$

Z-shaped membership function also is used in our senario.Figures,3.7 and 3.8 [31].

$$\mu_A(u)=\begin{cases}0 & \text{for } u\le d\\ \dfrac{u-d}{e-d} & \text{for } d\le u\le e\\ 1 & \text{for } e\le u\le f\\ \dfrac{g-u}{g-f} & \text{for } f\le u\le g\\ 0 & \text{for } u\ge g\end{cases}$$

Figure 3.5: Trapezoid-shaped membership experssion

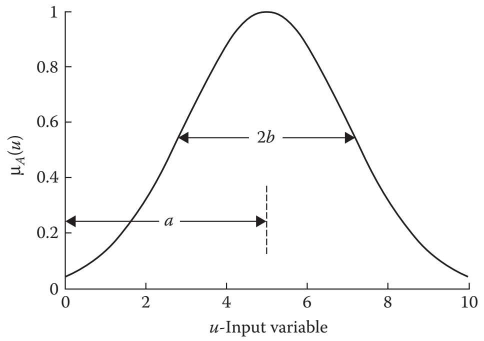

Figure 3.6: Gaussian-Shaped Function

$$\mu_A(u)=\begin{cases}1 & \text{for } u\le a\\ 1-2\dfrac{(u-a)^2}{(a-b)^2} & \text{for } u>a\ \&\ u\le \dfrac{a+b}{2}\\ 2\dfrac{(b-u)^2}{(a-b)^2} & \text{for } u>\dfrac{a+b}{2}\ \&\ u\le b\\ 0 & \text{for } u>b\end{cases}$$

Figure 3.7: Z-shaped membership experssion

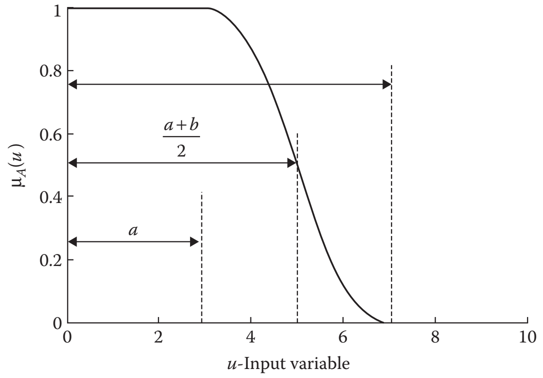

Figure 3.8: Z-shaped membership function

Chapter 4

Performance Evaluation and Simulation

4.1 Simulation requirments and limitations

This chapter represents the results of simulation based on framework that proposed in previous chapter. Simulations are implemented with Matlab R2011a software using some functions of communications system toolbox and statistics toolbox [29]. Basically, Simulations figured out with 32 sensor nodes as detector a event of interest,each node generates high traffic data rates. According to literature survey, most of related papers showed, they had used the Opnet simulator software with fully professional wireless sensor network package. Opnet software lets to simply design a network with unformatted and formatted data packets given us more accurate results[30]. Matlab software has restriction to design any complete system process whereas should design from zero, this means designer must implement many things far from the project goal to at last reach to own target. On the other side, this type of simulation force the designer more understanding projects dimensions and go deeply through of it.

4.2 Basic Issues

According to our framework at first steps, simulation started with stream bits sequence as a finite length vector generation for '32' detection sensors .we considered to four signal to noise ratio with QPSK modulation format and Gary coding.stream bits are modeled sensor detections of a binary phenomenon of interest. Length of stream sequence is 10,000 bits.for representing propagation of received bit sequences in signal constellation point which are located symmetrically on the unit circle in the complex domain, this gives more imaginary for received bits to fusion center based on different signal to noise ratio and in modulation format.however,model bit stream sequences as a complex signal vector could be can be expressed

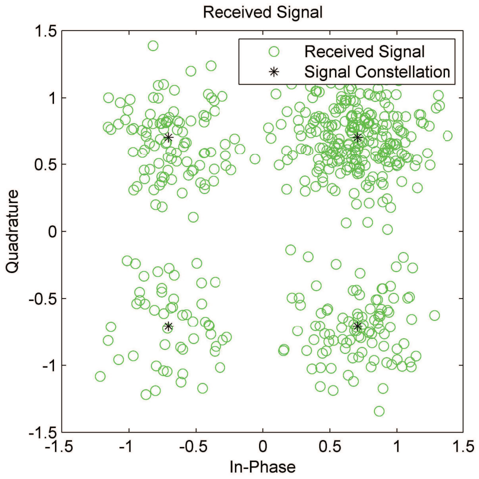

Figure 4.1: Bits stream,$snr = 3, 6$[dB],QPSK

by:

$$\tilde{s}_m = \sqrt{2E_h} e^{j\theta_m}, m = 0, 1, 2, 3.$$

where,$\theta_m \in \left\{\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}\right\}$ and E_h denotes the energy of the band-pass pulse $h_a(t).cos(2_c t)$,which given by,

$$E_h = \frac{1}{2} \int_{-\infty}^{+\infty} h_a^2(t) dt$$

where $h_a(t)$ represents the amplitude shaping pulse.due to signal constellation points on the unit circle ,we hypothesis the the energy of the amplitude shaping pulse is $\int_{-\infty}^{+\infty} h_a^2(t) dt = 1$. Now,suppose the sensors dectection is perfect and data transmitted through an additive white

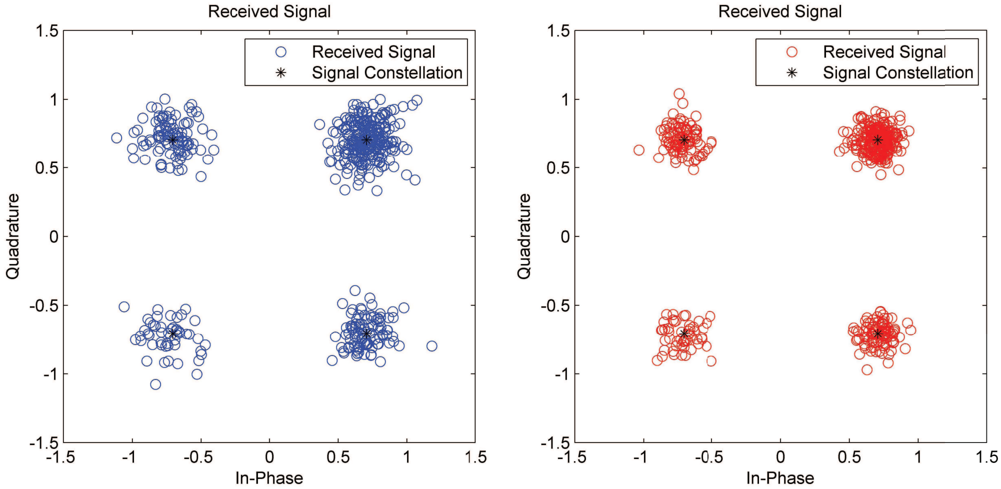

Figure 4.2: Bits stream,$snr = 9, 12$[dB],QPSK

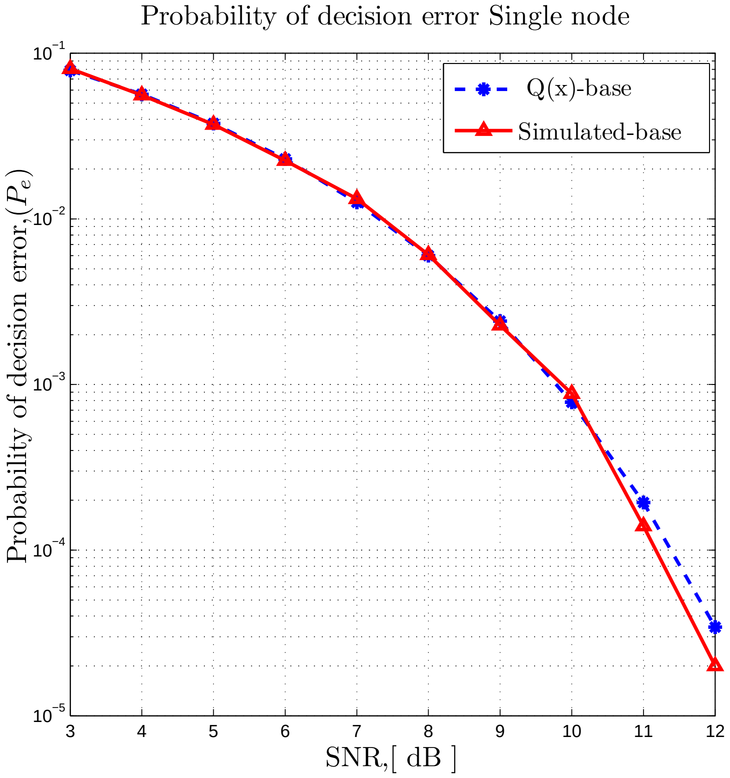

Figure 4.3: Decision error probability,P_e, for a single node

Gaussian noise (AWGN) channel.recived signal at fusion node are same as the sum of the QPSK signal and the white Gaussian noise,hence,generating a complex-valued white Gaussian noise vector whose length is identical with that of the QPSK signal vector.

Figures 4.1 and 4.2 are shown the propagation of Gaussian clouds signal sequences around original QPSK signal points.according to the SNR ,$E_b/N_0 = \{3, 6, 9, 12\}\,[dB]$,The SNR is defined as the ratio of the bit energy E_b to noise power N_0,we use *randint* function MATLAB communication toolbox for generating a binary bits sequence of $'0's$ and $'1's$ with equal probability and *npwgnthresh* function for NP-threshold both for Real and Complex-valued signals.The transmitted bits sequence with AWGN as a vactor receieved **r** to FC for decision making based on NP method by $\tau = \sqrt{snr}/2$.Probability of error at FC for both using $Q(x)$ funation and simulation based with NP method represent at Figure.4.3 for a single node.In situation is made decision with almost similar results of channel Bit Error Rate (BER) reasonably ,becuase of,if bits seqeunce receive to FC through channel with noise correctly, FC assumes definitely making decision perfectly.Wireless sensor networks employs the OQPSK for modualtion, 2.1,Offset quadrature phase-shift keying (OQPSK) using 4 offset values for phase transmission.It has some diffrence in specifications rather than QPSK but it also has same BER which is important in project. Subsequently,we will using OQPSK for modulation term.(At [33] will describe diffrences OQPSK ,QPSK).

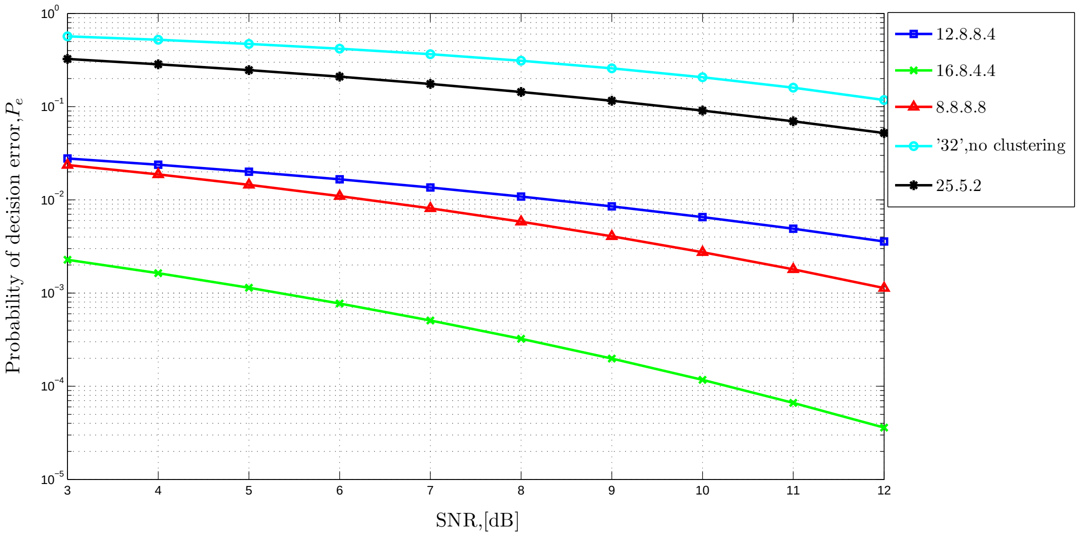

Figure 4.4: Probability of decision error as a function of SNR,$n = 32$ sensors with AWGN

4.3 Probability of decision error P_e clustering topology

In this section would be shown the simulation for evaluating probability of decision error in fusion center based on project framework in various topology.probability of decision error considered at fusion node with respect to clustering topology as long as presence of uniform and non-uniform distributions of '32' sensors.Three non-uniform distributions 12.8.8.4 , 16.8.4.4 , 25.5.2 are assumed and uniform distribution 8.8.8.8. Non clustering by '32' sensors are shown as a proof of comprasion in Figure.4.4.Figure represent to us the probability of decsision errorfor non clustring totloplgy which looklike a star network with coordinator ruling as fusion node. Detection sequences just affect with Additive White Gaussian Noise(AWGN) in OQPSK format modulation. Matlab awgn function is used with appropriated modulation as a percentage of received bits signal level at fusion with different signal to noise ratio taken into the account. Basically, increment of SNR has improvement on decision .according to various topology, figure shown that no clustering is worst case and 16.8.4.4 is best case, for an explanation, based on our scenario all nodes detect a constant binary phenomena represent as presence of PoI with 1 and absent with 0.Decision made at fusion based on vector received signals on majority-like strategy. Hence, in case of non-clustering should be received at least 17 sensors similar level to record as correct decision but for clustering this limitation reduces to half plus one $[d_c/2] + 1$ number of sensors at each cluster for example in 16.8.4.4 design by 4 clusters have 16,8,4,4 sensors respectively, therefore fusion node at head of clusters evaluated 9,5,3,3 sensors which should be have same level respectively for corresponding fusion node at head of clusters however in second level decision making at AP should be outcome of decision on first level 3 similar form 4 fusion nodes . Figure.4.5 is shown the probability of decision error with presence of P_{csi} and fading effect. Impact of P_{csi} and fading effect measured by attenuation on level of signal

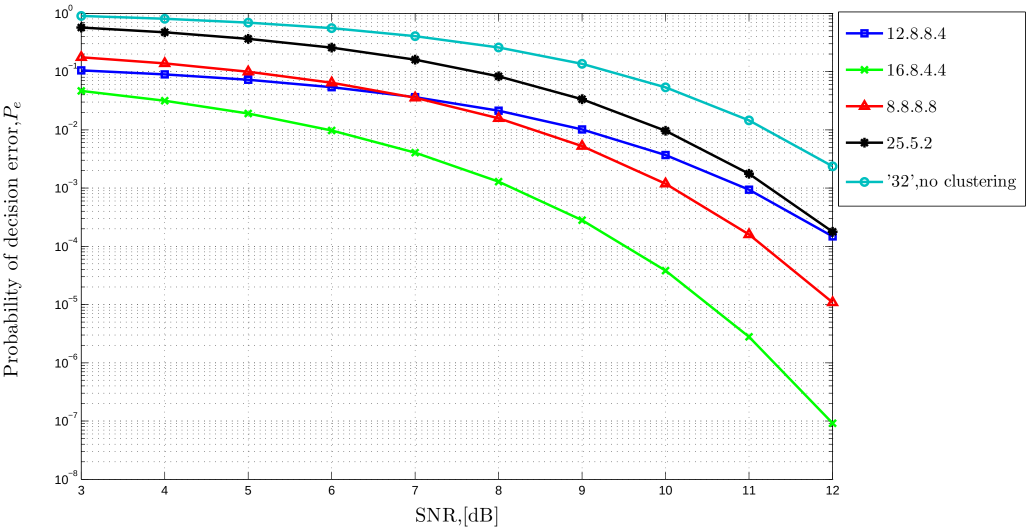

Figure 4.5: Probability of decision error versus SNR,$n = 32$ sensors with $P_{csi} + Fading$

with respect to assumption to change probability to percentage in order to reduce from level bits signal sequences. Indeed fading or P_{csi} in essence don't reduce level of signal or maybe increase the level signal but inefficient, hence we assumed the probability looks as percentages of those effects splitting from bit signals level.according to literatures Monte carlo simulation of corresponding experssions in framework given previous chapter also has approximately proof our simulation.Some related constant amount of assumation P_{csi} coming as table.4.1.

4.4 Performance metric evaluation based on Markov chain

Impact of MAC on decentralized detection,proposed a framework in previous chapter.regarding to performance metric evaluation simulation performs with implementation of Markov chain with non-liner equation with using the function handling method of Matlab. According to Table.4.1 and 4.2 Mac and Phy layers parameters denoted.OQPSK as modulation format is used with channel coding NRZ.more chnnel coding and modulation indicated in Tables.3.4,3.3. Performanc evaluated simulation consequence based on metric terms coming as follow:

4.4.1 Reliability

In term of Reliability evaluation base on chapter two and framework on chapter three, simulation carried out with using appropriated equations 2.10 to 3.43.Non-uniform and uniform topology is supposed with different number of sensors at each clusters in two level fusion. Model evaluated in high rate data generation rates. Three non-uniform implemented 16.8.4.4 ,25.5.2 , 12.8.8.4 sensors at each clusters .8.8.8.8sensor distribution,no clustering also implemented.no-clustering topology is similar with a star topology that originally was assumed by Markov

Parameter	value
Minimum distance	1 meter
Maximum distance	40 meters
Frame length	808 bits
Power Tx	3 dBm
pramble length	40 bits
Noise figure	-123 dBm
Noise	-5 dBm
Band width	30 kHz
Signal frequency(f)	2450 MHz
Path loss exponent	4 Table3.2
Shadowing standard deviation	4

Table 4.1: Parameters value for Physical layer

chain model.

Simulation results is illustrated in Figure.4.6 as funation of data generation with respect to vaerious topology.Basically signal to noise ratio as important term of decision making at fusion node is equal to $3dB$ and Modualtion format is OQPSK. result is shown a significant improvment in relaibilty in clustering topology even in two level of fusion in comparsion with no-clustering.however,in clustering based topologies balance of sensors distribution (uniform) in clusters are more reliable than unbalances(non-uniform).Figure.4.7repersented the relaibilty of system with signal to noise ratio equal to 12 dB with comparsion by 3dB.it shows a significant enhancment according to all appropriated topology. Relaibilty is enhanced in

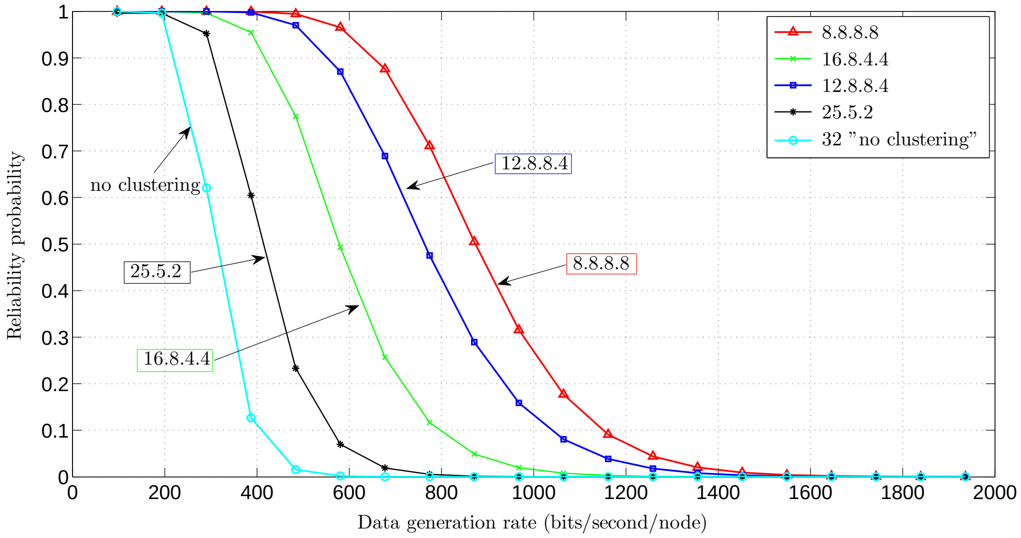

Figure 4.6: Reliability,$E/N_0 = 3$ [dB],OQPSK

Parameter	Value
MacMaxFrameRetries	3
MacMaxCSMABackoffs	4
MacMinBE	3
MacMaxBE	5
L	1016 bits
L_{ack}	88 bits
t_{ack}	222e-9 seconds
t_{IFS}	640e-6 seconds
$t_{m,ack}$	200e-9 seconds
aUnitBackoffPeriod	320e-6 seconds
macACKWaitDuration	1920e-6 seconds
aTurnaroundTime	192e-6 seconds
S_b	128e-6 seconds
L_0	10e-12
q_0	10e-12

Table 4.2: Parameters value for MAC layer

order to increment of signal to noise ratio. Due to direct relation between probability of success packet reception or reliability with probability of packet failure, improvement in failure has consequence of improvement on reliability, improvement of failure meaning to reduce the probability of packet failure.Figures.4.8 and 4.9 are illustrated reducing failure in term of snr increment.Hence,we should expect to enhancement on reliability.

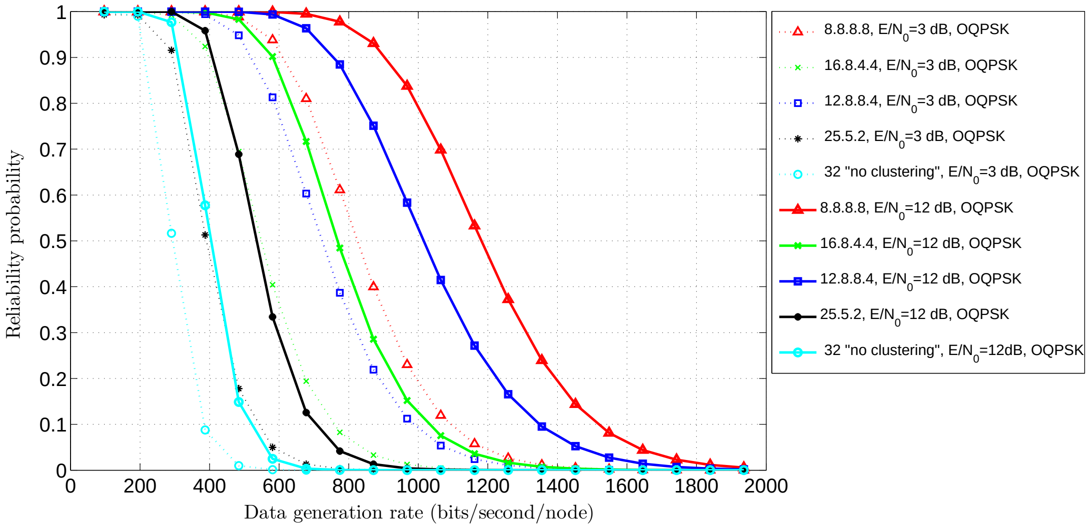

Figure 4.7: Reliability,$E/N_0 = \{3, 12\}$ [dB],OQPSK

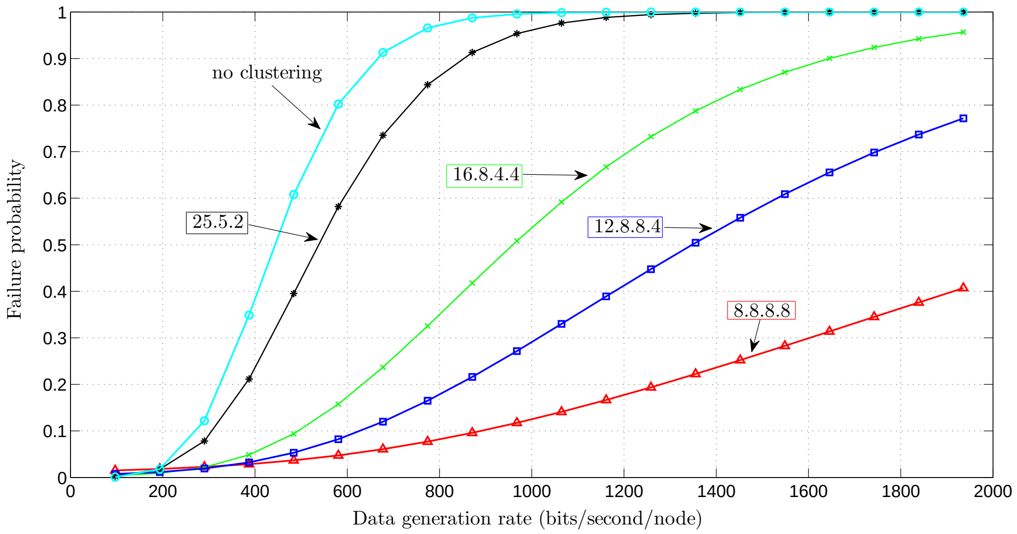

Figure 4.8: Failure probability,$E/N_0 = 3$ [dB],OQPSK

Probability of packet failure is simlulated equations 2.11 and 3.39.Incresment snr from 3dB to 12dB causes less failure packet reception at fusion node. Result presented in probabilty of decsion error P_e also proof this improvment at FC.however,packet failure is increased versus packet generation rate,so we can say high packet genaration rate more effective than incresment of snr ratio in probability of failure.

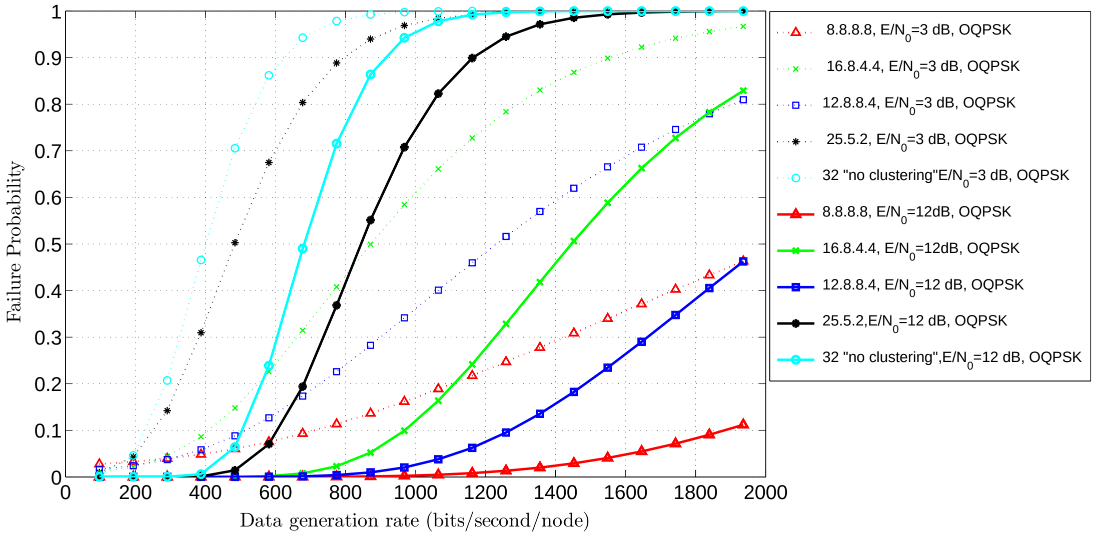

Figure 4.9: Failure probability,$E/N_0 = \{3, 12\}$ [dB],OQPSK

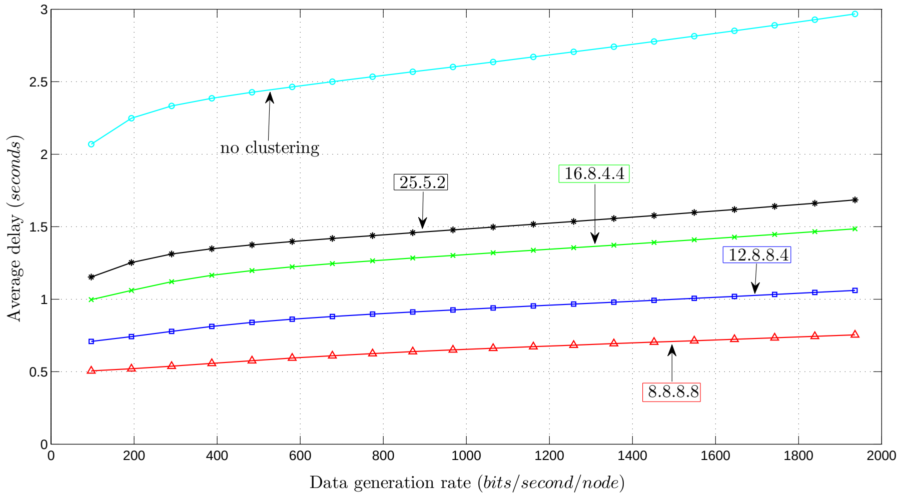

Figure 4.10: Average delay for two levels decision,$E/N_0 = 3$ [dB],OQPSK

4.4.2 Average delay

Measurement of average delay explained in framework. Simulation performed based on packet generation rate with two snr = 3,12 dB .Important issue here is synchronizing between nodes that is done by specify a slot time from FC to nodes for retrieve data. Obviously, this time slot is corresponding to size of each cluster .Therefor, time slot cluster with 8 sensors is forth time greater than time slot for cluster 2 sensor because of preventing collision in each cluster during transmitting. Then each node per cluster has own time slot to send. Clusters are independent from each other and transmitting in their appropriated bandwidth. IEEE 802.15.4 has 16 channels in 2.4 GHz , based on simulation with maximum 4 clusters , there is not any constrain in bandwidth scheduling but each cluster works in a unique bandwidth. Hence, for retrieve data slot time scheduling must be done. Slotted Markov chain model specification satisfies the condition. Slotted based transmitting scenario also proof our simulation results which are represented in Figure.4.10.Non-clustering topology has more average delay.That delay is imaginable because of time slot scheduling scenario for 32 nodes need biger time slot length.Even with two level fusion average delay of topology without clustering is higher than clustering. According to distribution of sensors uniformly or non-uniformly are explainable with time slot senrio. Uniformed 8.8.8.8 needs a time slot with 8 portions for each retriving data process.However ,others need at least one cluster biger than a time slot with 8 length.Basiclly,effect of number sensors on α and β and τ are important ,exactly contribution of less sensors cause increasing probability of access channel and directly reduce delaies. Figure.4.11 illustrates the average delay according to snr = 12 dB. Figure is shown a reduction in average delay. Due to less packet failure in 12 dB , amount of packet retry absolutely reduced then measured delay directly reduced.Two fusion levels considered then senario valid between AP and FCs.Distance between transmitters and receivers are same for all toloplgies and assumed in implementation.

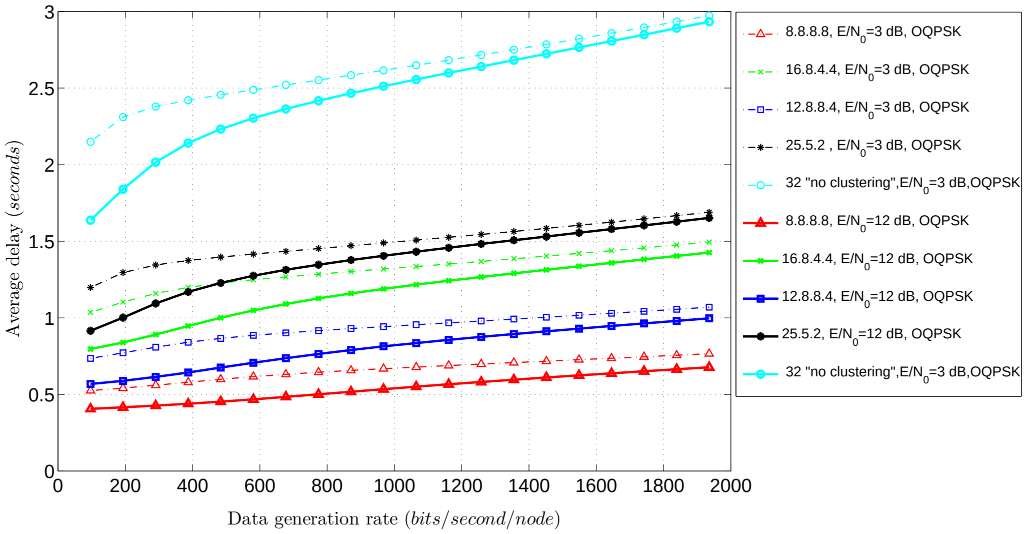

Figure 4.11: Average delay for two levels decision,$E/N_0 = \{3, 12\}$ [dB],OQPSK

Waiting delay in queue and ACK back delay also considered.

4.4.3 Network aggregate throughput

Network aggreagte throughput implementation are shown in both Figures.4.12 and 4.13 as data generation rate with two snr ratios.Throughput as function of reliability explained in framework description chapter.All issues are showing improvement in higher signal to noise ratio but here we have throughput reduction in 800 bits per seconds in each node. According to failure

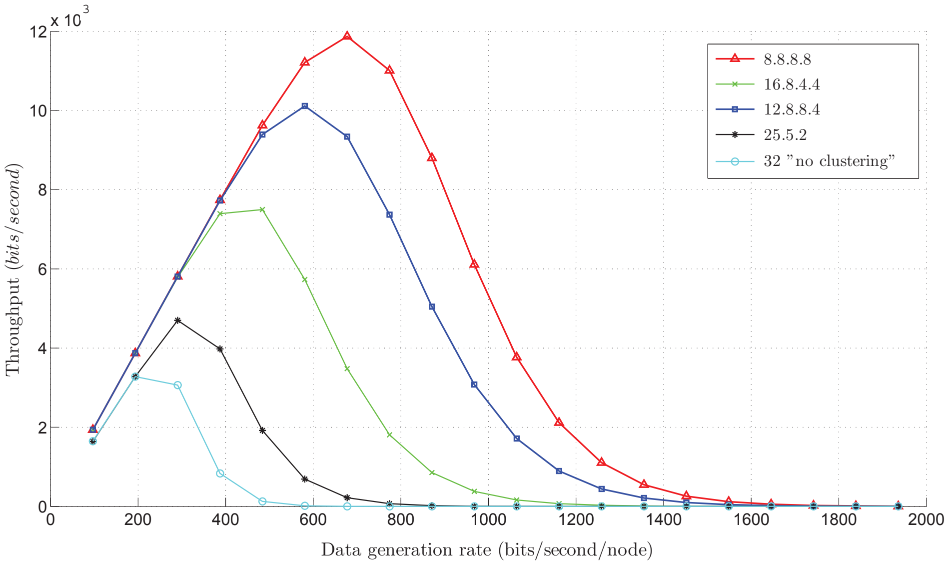

Figure 4.12: Throughput,$E/N_0 = 3$ [dB],OQPSK

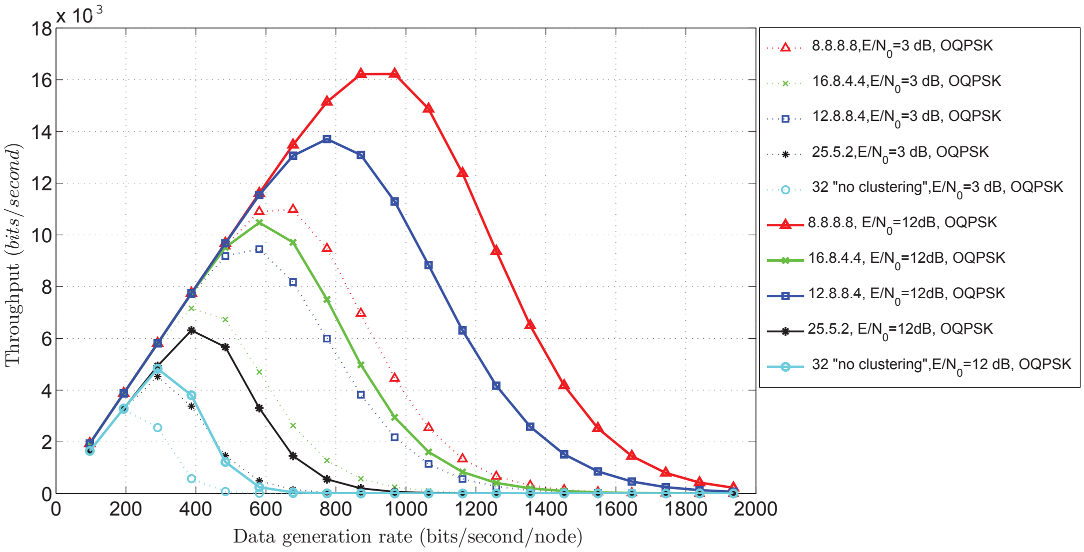

Figure 4.13: Throughput,$E/N_0 = \{3, 12\}$ [dB],OQPSK

and reliability with relation of this performance metric parameter behavior is conceivable.we suppose the evaluation of throghput in minimum number of effective sensors for fusing data at each cluster.

4.4.4 Average power consumption

Evaluation framework was explained for network average power consumption. Simulations results are shown Figures.4.14 and 4.15. Increment of mean power consumption with higher data generation rate obviously illustrated. More power using to transmission issue rather than

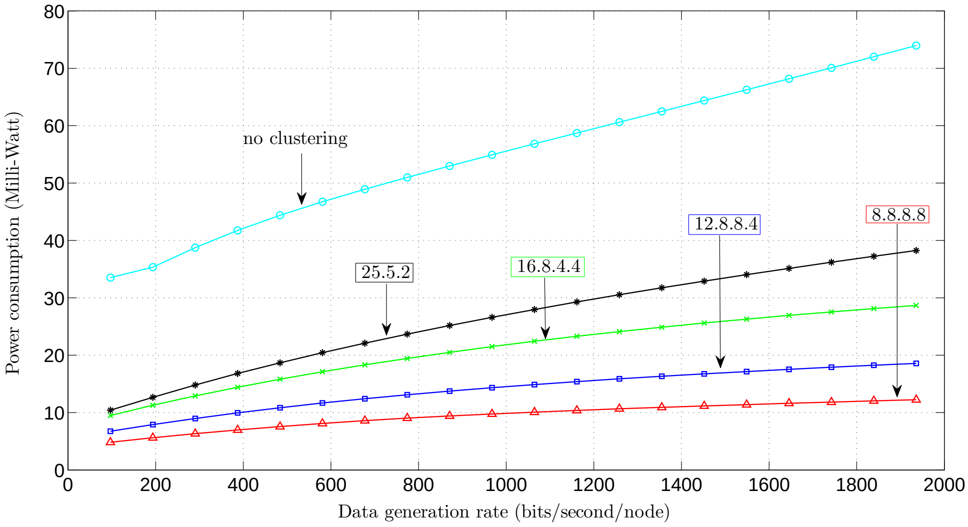

Figure 4.14: Average power comsuption,$E/N_0 = 3$ [dB],OQPSK

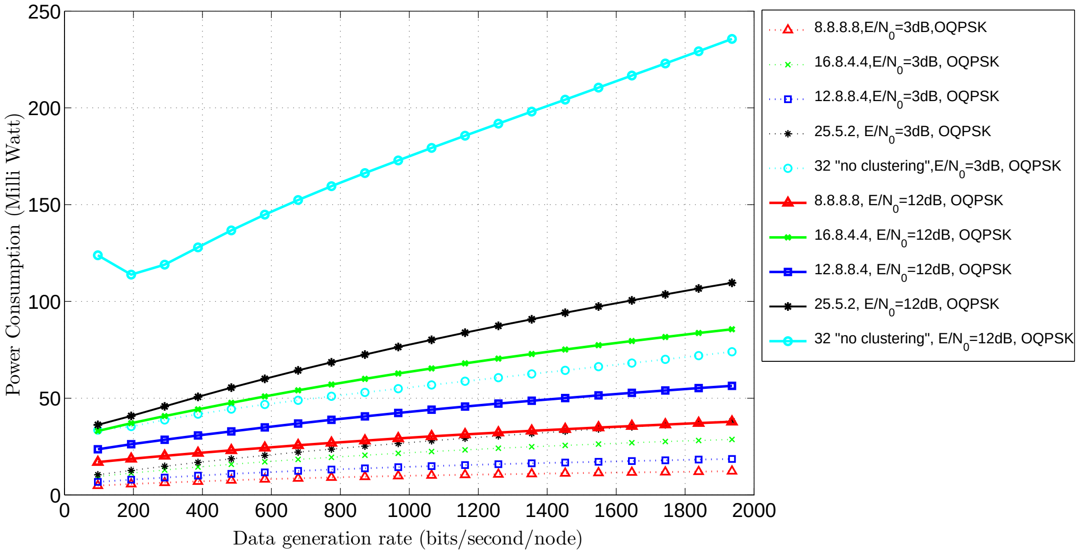

Figure 4.15: Average power comsuption,$E/N_0 = \{3, 12\}$ [dB],OQPSK

computational matter in sensor module.Two fusion levels was considered which consumes more power one level.Nevertheless, number of sensors has critical rules in got such results. Topology without clustering 32 sensors contribute in decision making in on fusion node coordinator at least need half plus one and more on sensors. Clustering topology distribution of sensors was effected in computation. According to term defined for power consumption equation 2.18 rules of α,β and P_c are important because of definitely, probability of access to channel α, β for a cluster by less sensors is more than non-clustering topology and term of P_c is smaller than non-clustering therefor, E_{tot} of clustering is smaller than non-clustering in general. Average power is increased with 12 dB signal to noise ratio due to obviously transmission power, P_s .base on table of power in chapter two a constant denoted for transmission or receiving power. During simulation we assumed a snr in especial modulation acts as a coefficient then results has understandable interpretation.while to power consumption is very critical issue to wireless sensor network,increment of power consumption is harmful with respect to restriction on battery capability.on the other view,preciseness of packet receipt sometimes is relying on power consumption.

4.5 Fuzzy logic for a coverage inquiry

Implementation of fuzzy logic fusion performs by using toolbox fuzzy logic in Matlab GUI. Fuzzy Interference system (FIS) is done with two input as distance (m) and snr (dB).Table.4.1 represents some constant value.Distance is range: 1 to 100 meters and snr is : 3 to 12 [dB].inference performs Mamdani Method. Gaussian membership function,Z-shaped membership function,Trapezoid-shaped membership function use to definng input value of SNR,input

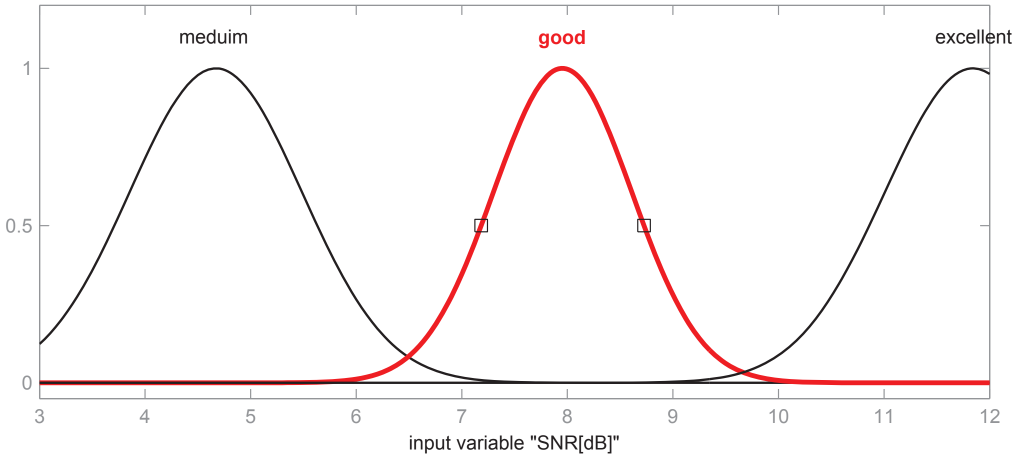

Figure 4.16: Gaussian membership function SNR

value of distance and output value of coverage,respectively.schematic of membership functions are used in simulation shown in figures.4.16, 4.17 , 4.18.Rules are appropriated based on mamdani inference method.different range of SNR and distance and coverage tagged with special names which are explianing behavioral of fuzzy parameters in corresponding ranges.'18' rules are implemented with 'AND' logical operator to specify output.Inference opreands method as defaults lists as follow:

Or method = min,

AND method = max,

Implication = min,

Aggregation = max,

Defuzzification = centriod.

Base on rules are definted,Percentage of coverage is shown in Figure. 4.19.

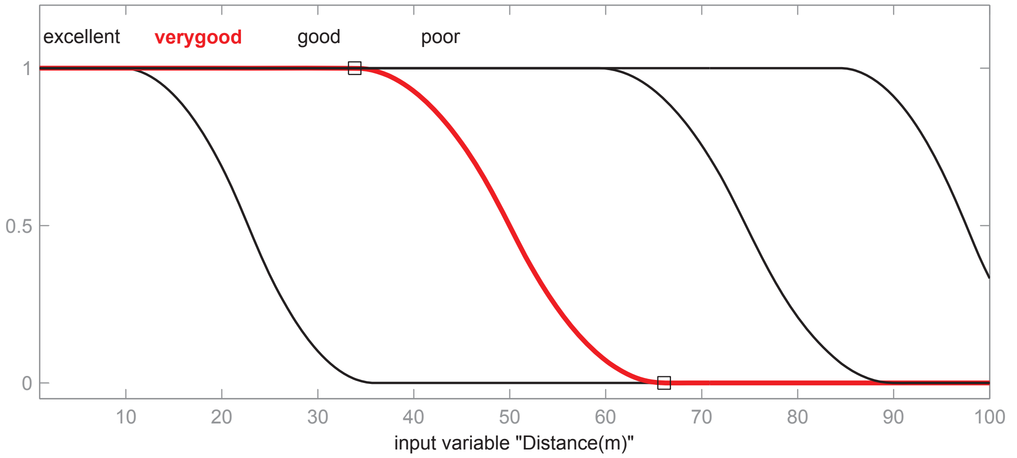

Figure 4.17: Z-shaped membership function distance

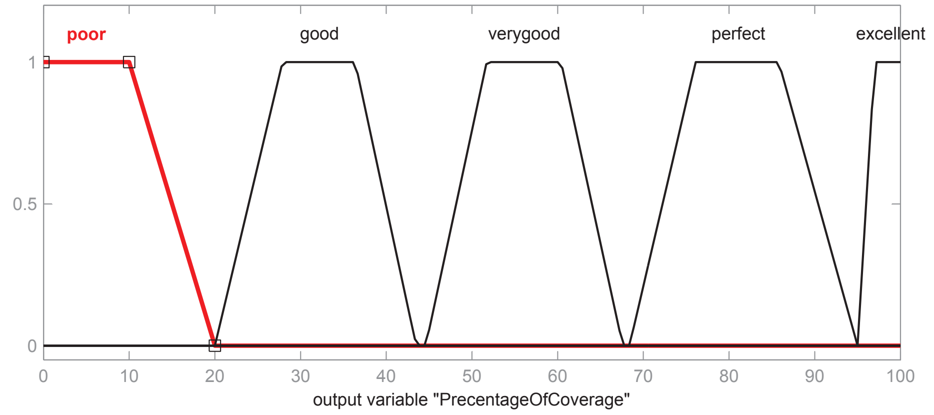

Figure 4.18: Trapezoid-shaped membership function percentage of coverage

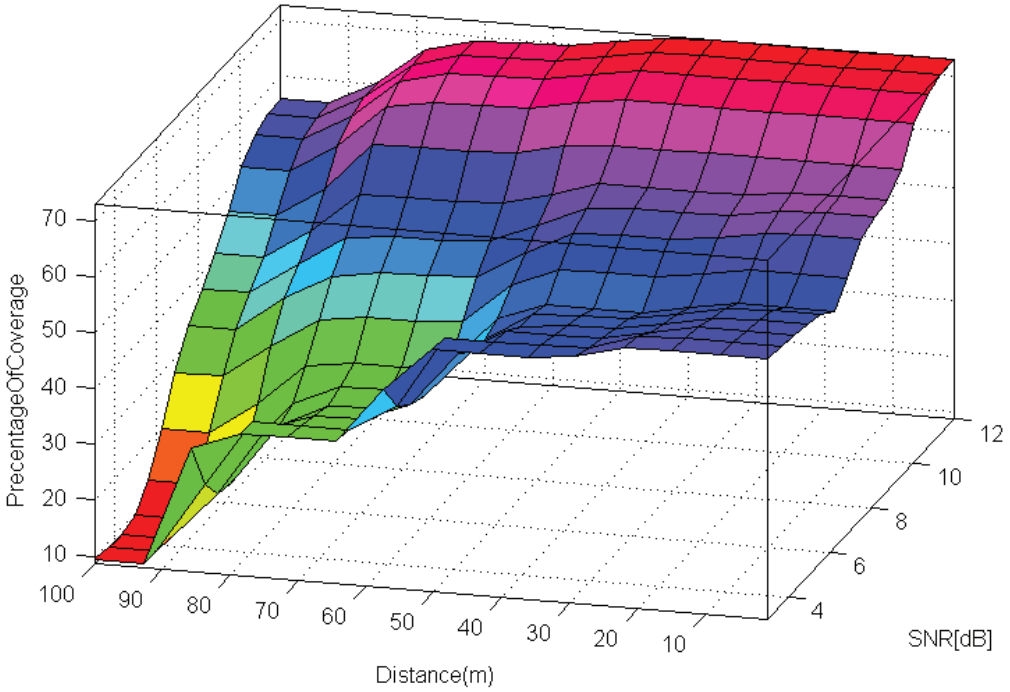

Figure 4.19: Precetage of coverage as function of SNR,distance

Chapter 5

Conclusion and Discussion

The aim of project was calibrated on performance metric evaluation based on information fusion application on wireless sensor network.In fact, theory and performance evaluation framework explained at chapters two and three. Chapter four has consisted of simulation results with description note. High traffic data rate and signal to noise ratio as two important parameters considered. Analytical Markov chain model is depicted behavior a single node in network with N sensor and star network topology. Probability of Channel State Information(P_{csi}) as term of distance between transmitters(sensors) and receivers (Fusion node).OQPSK format and Channel coding NRZ were assumed as common modulation scheme in IEEE 802.15.4 physical layer and encoding respectively. Performance metric evaluated in framework by both snr = 3,12 dB. Rayleigh fading in appropriated modulation in order to fading channel Bit Error Rate (BER) integrated with P_{csi} and also impact on Markov chain model performance metric expressions are investigated.

5.1 Concluding Remarks

No doubt, ultimatum concluding about performance based on the results which obtained only in this project as exact and certain evaluation of performance is not completely correct.However, related literatures survey also were representing the similar conclude according to parameters usage. Sometimes, performance evaluation metric parameters acting opposite side of each other. For example, as defining Reliability, probability successful packet reception enhanced with more power consumption which is unwilling matter is low-power wireless sensor network. Fusion nodes decision making were improved in term of power consumption which is presenting in signal to noise ratio. Generally speaking data fusion with cluster base topology has better performance with respecting to our assumptions, targets and using model rather than no-clustering. Presence of uniform clustering with balance distribution of sensors per clusters acting better than non-uniform clustering with more number distribution of sensors for each cluster. Average delay effects directly from face of distribution sensors in clusters.Throughput has better outcome in cluster base with balance distribution sensors in uniform topology.Power consumption as discussed previously has been acting better in balance uniform distribution topology instead of non-uniform clustering and no clustering as well.

Coverage or connectivity investagtion with fuzzy logic fusion method illustrates direction relation between distance and applied SNR raito.According to distance between transmitter and receiver should be tune with more transmission power consequently increase SNR,therefor based on simulation network has more coverage and less BER and also reduce the probability of decision error at fusion node and AP for both levels of fusing,respectively.

5.2 Further works

Project has been done with basic hypothesis.so many ideas are possible to implement while the application of wireless sensor networks are vary. Information fusion applications in WSNs possible to define in difference manner. As view of proposed further works, non-constant phenomena with fluctuation sensing condition or target in motion for example vehicles taken into the account. Maritime system with connection with radar and satellites are as very significant application of information fusion with integration local wireless sensor network on ship could be considered. In e-health system could be a application of data fusion methods for gathering data from sensors e.g. on patient body.Controlling remotely home security issues with installed sensor , conditional monitoring a process in factory or smart automation system, inside of cars motor, Radio Frequency Identification(RFID), production of 3D movie with scanning body of actors with fusing multi-sensors and many more others are potentially active fields for *' Application of information fusion to wireless sensor network'.*

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