ORIGINAL ARTICLE

Smart Embedded Wireless System Design: An Internet of Things Realization

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Abstract: Internet of Things (IoT) is an explosive technology that has enhanced the performance of sensor networks and transformed wireless communication through the interconnection of smart devices and cognitive systems. Despite the numerous innovative solutions and technological benefits realized by the adoption of IoT, some of the persistent challenges of the IoT smart technology design is the component integration issue (scalability) during the hardware design phase. Also, power consumption, interoperability difficulties, end-to-end communication lag, and quality of services (QoS) deterioration. This research therefore addresses these challenges by systematically investigating and analyzing the selected factors and relevant performance indicators. It also gives a clear and cohesive description of the proposed IoT design model together with the pertinent systemic component's communication. The design requirements and technical procedures for integrating embedded devices, sensor networks and wireless data communication for the enhancement of the proposed IoT architectural model is also elucidated in this work.

Keywords: Communication, embedded system, interoperability, quality of service (QoS), sensors, smart system.

Introduction

The significance advancement in smart embedded wireless system (SEWS), has improved communication and interactions between human and things in the universal networks. This include remote control and monitoring system, real-time data acquisition and surveillance of the environments. Today, the technology of 6LowPAN platform using internet protocol version 6 (IPv6) addresses and its infrastructures has simplified the present challenges of universal network with regards to connectivity amongst humans, things, objects and also machine-to-machine interactions. This concept of IoT model with support of 3G, 4G and 5G networks arrival has contributed to the world communication, connectivity and interoperability among varieties of electronic gadgets, home appliances, and between humans on the world-wide link [1].

Internet of Things (IoTs) is defined as a worldwide network facility with self-configuring capabilities based on standard communication protocols where physical and virtual things have identities, physical attributes and virtual personalities that use intelligent interfaces to integrate the information into the network [2]. The Global Standards Initiative on Internet of Thing (GSI-IoT) in 2013 identify IoTs as the infrastructure of the information society and controlled them remotely over the available network communication. It helps to create more opportunity for the integration of physical world and computer ecosystems, which resulted in enhancement platform and better economic practices [3].

The industrial production of smart embedded wireless system for remote sensing, monitoring and controlling in the smart paradigm such as smart home, smart city, smart agriculture, smart car, smart transportation, smart devices (like phones, PDAs, tablets, laptop and others), smart factory, smart healthcare, and so on has been focusing [4, 5]. Also, the implementation of smart embedded system (SES) are widely developed with various smart sensors and wireless connectivity like RFID, Wi-Fi, Z-waves, Cellular network, Bluetooth, ZigBee to render services of a remote sensing and control. These integration of facilities in embedded system-based internet of things has been utilized to achieve various levels of intelligence, decision making and remote monitoring [6].

Therefore, the universal network technology known as (IoT) substantiate its usefulness in the world of connectivity which provides conveniences, comforts, security, and quality of life over the communication that exist between things and people, machine to human (M2H) and between things themselves.

The term smart technology refers to the physical and logical format that can be adapted automatically to suit the environmental condition using various sensing technology (sensor) which ranges from pet passenger trackers, car geo-location monitoring (using GPS), door access control and security measure (using RFID card). Smart technology as a green information that connects several combinations of industrial technology (IT) products represent different things to different people in the ubiquitous platform [7]. Several wireless technologies and protocols were proposed and developed by Institute of Electrical and Electronics Engineering (IEEE), Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T), Internet Engineering Task Force (IETF) and other organizations for the enhancement of interoperability, interconnectivity, scalability, heterogeneity and security.

Literature Survey

Several researchers have proposed and discussed different ideas on internet of things paradigm and its related technologies as new interest of investigation for both academician and industries [8].

In [9], a mobile gateway-based internet of things architecture for the realization of home automation and car navigation system was proposed. Smartphone devices was used as a gateway system to provide tethering function for the heterogeneous system in IoT ecosystem with independent connectivity location. This system does not require a special supplementary IoT device for subscription. Although, the architecture proposed is efficient since it utilize web-platform but is resulted in data delay, asynchronous status and protocol overhead.

A smart sensing system architecture and efficient energy actuation was described in the tutorial of [10] where mathematical modelling for autonomic data driven is developed for remote data sensing which assist to overcome energy challenges in the wireless sensor network based IoT. The design consideration for efficient energy architecture was defined for incoming stream of metadata and communication devices. Reconfiguring techniques for plug and play of numerical control system was used. This method helps to achieve a low energy system design as it decentralized the architecture using ARM Cortex-M3 development board.

The internet mail access protocol (IMAP) was proposed in the research of queuing theory modelling and communication-based IoT [11]. This work aims to reduce all overhead application management of user's email system by keeping several records of a particular notification related to the business. The machine to machine queuing architecture with mathematical proof of concept model is employed. This method helps the user to classify electronic inbox mail by providing security mechanism for privacy maintenance and other issues occurring.

Many of the universal networks' architecture based on WSN-IoT have been developed to tackle most of the common challenges in the design architecture of remote health monitoring as in [12], home automation control, surveillance and monitoring using android apps for remote control [13], as well as in monitoring of physiological environmental parameters for improvement in agricultural products and weather forecasting [14, 15].

A well-defined architecture and protocols for smart technology in considering of low energy consumption, and end-to-end communication with quality of services has been developed in [16, 17]. The architectural design wireless connectivity, android-based web applications and protocols to meet up with some of serious IoT challenges. Therefore, numerical and advance mathematics modelling-based Internet of Things was discussed in [18]. This mathematical computation ideas assist greatly in the theory, mathematical evolution and experimental design of IoT applications.

This research focuses on the smart embedded system technology design for the IoT platform, by identifies some factors that affecting efficient performance of the framework during end-to-end (e2e) communication, routing of packet, and its scalability.

1. Analyzing different routing algorithms that are efficient to overcome the data routing techniques problem in a smart embedded wireless system.
2. Discussed abstract model for embedded wireless system based IoT design.
3. Perform a simulation for sensor node

communication model and analysis, which it was benchmark using packet generation (packet/s), throughput (Kb/s), packet loss (%) and average packet delay (bit/s) as a metrics.

Consideration and Challenges of Smart Embedded Technology Design

The design of these smart embedded wireless technology depends on hardware design, software coding and control theory with holistic approach of computation to suit physical environmental constraints. For instance, a typical mote in a wireless sensor network (WSN) consists of sensor nodes, microcontroller unit (MCU), and a wireless transmission device (radio frequency (RF) circuit). This mote is mostly powered using lithium battery or other means of energy and is very hard to replace. Then, the power consumed during sensing and packet transmission are the critical stage constraints in embedded wireless system (EWS) based IoT which shorten the longevity of a sensor node. Others are hardware components that involved in the designed architecture. Particularly, the internet of things gateway (IoTG) called radio or routers which consume maximum amount of power during packet transmission and receiving as illustrated in Figure 1.

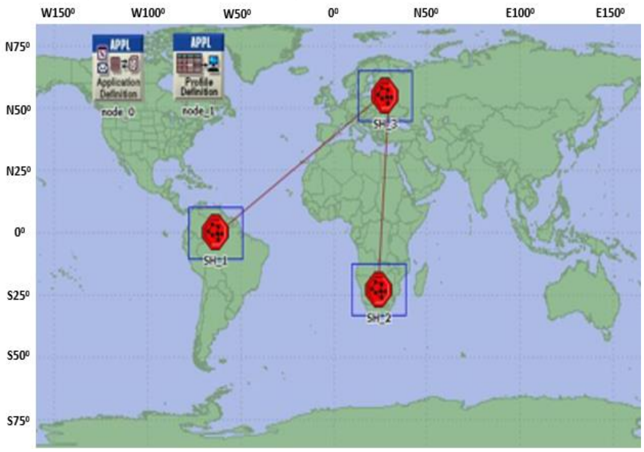

Figure 1. Wireless sensor node based IoT configuration

So, it is very significant to be enlighten on these factors that affect efficient design and performance of smart embedded wireless system in a pervasive or called universal network. This includes fault tolerance and reliability, scalability, hardware constraint, network topology design, operating environment, transmission media, routing algorithm techniques and energy consumption.

Fault Tolerance and Reliability

Fault tolerance is the ability to sustain system functionalities without any interruption, or failure that occurs in any part of the system. This failure occurs as a result of environmental interferences, physical damages or energy source depletion which in norms circumstance should not affect the network.

Reliability *R(t)* can be described as the probability of a system that will continue to survives until it become unreliable (failure) *F(t)* as expressed in (1). The unreliability of the system and the probability that an embedded system will not fail within the interval (0, t) are expressed as in (2) and (3).

$$R(t) = P(X > t) = 1 - F(t) \qquad \textbf{(1)}$$

$$F(t) = 1 - R(t) \qquad \textbf{(2)}$$

$$R_j(t) = e^{-\lambda_j t} \qquad \textbf{(3)}$$

where, X is the random variable of the component lifetime, P is the probability, λj is failure rate of node, j and t is interval period (time).

Scalability μ(S)

Scalability is the ability of extending or increasing the size of a network nodes without collapse the network structure and services. It is a process of adding more sensor nodes to a network and still maintain its efficiency even when several numbers of nodes were added to it. Therefore, a scalable network is a network model that grows with increasing in network loads. Scalability of a network system can be calculated as expressed in (4).

$$\mu(S) = \frac{M\pi T^2}{E} \qquad \textbf{(4)}$$

where, *M* is the number of scattered sensor nodes in the network environment *(E), T* is a transmission radio range, and *E* is the network environment.

Hardware System Design

Hardware system design refers to the parallel integration or interconnection of the components, where each of the component perform their specific function as proved in the (equations) analytical models. The hardware component implementation is configured with coding techniques (computational models), which leads to constraint in processor speeds, memory capacity for data storage, power utilization and hardware failure rates. The embedded wireless system includes integration of hardware components as a full-functional-device (FFD) such as microchips, memory, processors, power and others as depicted in the block diagram of Figure 2. They are capable of processing and executing data, scheduling of task, configuring node for packet forwarding, reception and management. This system design may also include additional unit like global positioning system (GPS) for location detection.

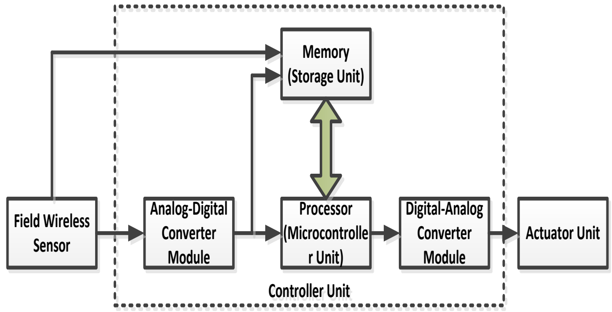

Figure 2. Block diagram of embedded wireless system.

Network Topology

Network topology is a models or structural linkage designed for controllability of both internal and external sensor nodes, which are interconnected to capture or sharing empirical properties in a network. Therefore, this topological properties in relating information and profile control between source and sink nodes, distribution of services in a network are constraints when integrated within embedded wireless system based IoT. This constraint challenges are as a result of complexity of the system (density of nodes) and interaction between pairs of nodes connected (unweighted edges components). Therefore, a suitable topology is important to be adopted for the efficient communication in the network due to various number of sensor nodes involved in the network for surveillance, tracking and monitoring.

The following are most common network topologies used, (includes star, tree, mesh and hybrid). Each of this topology has the challenges and better performances on the network as analyzed in Table 1, based on their communication range, power consumption rate and synchronization period required by the sensor node.

Table 1. Network topology analysis.

Topology	*Communication Range*	*Power consumption*	*Synchronization period*
Mesh	Long	Higher	Not at all
Star	Short	Low	Not at all
Tree	Long	Low	Yes
Hybrid	Long	Very low	Depend on sensor pattern

Data Model Design

Data model refer to the application requirements for the control of low latency, reads and write data with pre-defined pointer into a data block. This block of data model required different data types with pre-defined schema to store data or list of values sorted in a table. It includes primitives, collections (lists, maps and sets), primary key, key space (collection of related tables) and so on [19]. As a result of these descriptions shown in Figure 3, efficient data model design for embedded wireless system is a critical aspect of the smart technologies.

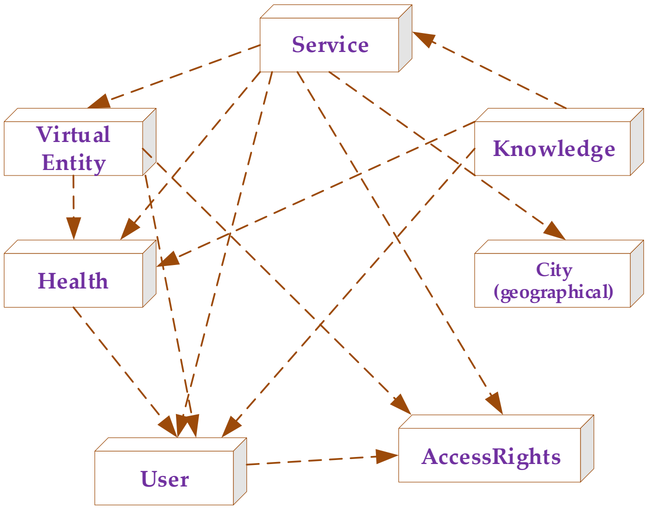

Figure 3. IoT data model design networks.

Operating Environment

The wireless sensor node is expected to be effectively designed for the efficient operations, and adaptation with environmental condition when they are densely deployed directly in contact with the phenomenon or closer to the object. This includes underwater acoustic monitoring, surveillance in battle fields, harsh condition like nozzle of an aircraft engine and so on. The formation of wireless connections and network services in varying environmental conditions as a result of atmosphere/weather, rain and icing conditions are threats to the system performances.

Transmission Media

Signal transmission media is very important and crucial to any EWN development which adopt available global media such as radio frequency (RF) and Industrial Scientific and Medical (ISM) band. In wireless communication systems, the frequency used for transmission affects the amount of data and the speed at which the data can be transmitted. The strength or power level of the transmission signal determines the distance over which the data can be sent and received without errors or loss of signal. In general, the principle that governs wireless transmissions dictates that a lower channel frequency can carry less data, more slowly, but over a long distance. The distance between the center of cell that use the same cluster frequency shows the cluster size C and cluster cell. The frequency reuse distance (f_{rd}) is used to normalize the size of each cell in hexagonal shape as expressed in (5) & (6).

$$f_{rd} = sqrt\ \{3\ \ C\} \tag{5}$$

$$C = \ \ i^2 + ij^2 + j^2 \tag{6}$$

where, *C = 1, 3, 4, 7, 9, …* as imaginable cluster size or single cell size, *i, j* are integers that determine relative location of co-existing channel cells. Therefore, the equation can be rewrite as (7).

$$f_{rd} = sqrt\ \{3(i^2 + ij^2 + j^2)\} \tag{7}$$

The effective power transmission between the antenna transmitters to the receiver ($P_r,\ P_t$) through the antenna area and their directivity ($Dt,\ Dr$) are expressed as in (8), (9) & (10).

$$\frac{Pr}{Pt} = \left(\frac{a_r a_t}{d^2 \lambda^2}\right)^2 \tag{8}$$

$$\frac{Pr}{Pt} = DtDr\left(\frac{\lambda}{4\pi d}\right)^2 \tag{9}$$

$$P_r = \ \ P_t + \ \ D_t + \ \ D_r + 20\ \ log_{10}\ \ \left(\frac{\lambda}{4\pi d}\right)^2 \tag{10}$$

where, A_r and A_t is effective radio antenna area for receiving and transmitting signal, d is distance between radio antennas, λ is radio frequency antenna.

Energy Consumption

A battery life of EWS can be significantly extended if sensor nodes are configured to coordinate or dictate when the entire circuit should ON or OFF or by using meta-heuristic algorithm as in [20, 21]. Therefore, a sensor node in an EWS can be configured to determine when the entire circuit should begin monitoring of an event, by activating the circuit or else should put to deep sleep mode for energy savings.

The lifetime of WSN is highly dependent on the power available at each node in the network called active power ($Active_P$), when this power is drain off during operation without any reserve energy is refers to as energy constraint in embedded wireless system. The average power (Av_P) consumption in a sensor node and the sensor node duty cycle (D_{node}) which is the fraction of time (t) when the node is active and the period *(T)* can be expressed as in (11), (12) and (13).

$$Av_P = Active_P * D_{node} \tag{11}$$

$$D_N = Active_t/T \tag{12}$$

$$T = Active_t + Sleep_t \tag{13}$$

Routing Techniques

A wireless sensor network performance relies on its network layer's and routing algorithm adopted to discover best routes to ensure packets transmission delivery to the destinations. The transport control protocols/internet protocol (TCP/IP) are mostly responsible for guarantee packet delivery and established a reliable communication connection between two hosts in a network. It also repairs and maintain the routes disruption when radio links (or hops) along established routes broken. This problem can ensue due to sensor relocation or nodes failure, server radio frequency (RF) interference and congestion. The routing algorithm techniques usually assist embedded wireless sensor node to be self-organized in the field environment as discussed in Table 2.

Also, the routing processes in the network is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad-hoc networks as in Table 3. These includes building of global addressing and routing algorithms for classical IP-based protocols. The application of sensor nodes in the network is to sensed data from multiple regions (sources) and route to a particular sink or gateway (destination) which consume energy and bandwidth utilization. Therefore, the nodes that are tightly deployed in a constrained network environment will have limited or constraint resources like power consumption, processing capacity and data storage. The HEED and LEACH energy aware routing protocols [22-24] is functions as a multi-hop routing network algorithm using transmission power of inter-cluster communication to selects cluster head (CH) among the sensor nodes in a network [32] and is expressed as in (14).

$$\text{ƕ}_{prob} = \text{C}_{prob} * \frac{\varepsilon_r^i}{\varepsilon_T} \tag{14}$$

where, ƕ_{prob} is the probability of selecting a sensor node as a cluster head, C_{prob} is the maximum number of clusters probability in the network, ε_r^i is the residual energy of an *ith* node, and ε_T is the total energy of the network.

Table 2. Routing algorithm analysis

Routing algorithm	***Classification***	***Power transmission***	***Data aggregate***
LEACH [22, 23]	Hierarchical	Stable	Sure
EWC [24]	Hierarchical	Stable	Sure
SPIN	Data centric	Stable	Sure
REAR	Data centric	Modified	Sure
Energy aware [25, 26]	Data centric	Modified	Sure
Direct diffusion [27]	Data centric	Stable	Sure
Information driven	Data centric	Stable	Sure
Gradient	Data centric	Stable	Sure
PEGASIS [28]	Hierarchical	Stable	Sure
Energy-aware based cluster head [29, 30]	Hierarchical	Modifiable	Not
Self-organized	Hierarchical	Stable	Not
Minimum energy comm. Net.	Hierarchical	Modifiable	Not
Geographic Adaptive Fidelity	Location	Stable	Not
Geographic and energy Aware [31]	Location	Stable	Not
SPEED & MMSPEED	QoS	Stable	Not
EEDG [32]	QoS	Fixed	Sure

Table 3. Routing algorithm and its functions

Protocols	*BS N*	*Mobility*	*Functions*
LEACH	1	Stable BS	Distributed cluster node is formed to extend nodes lifetime.
EWC	1	Stable BS	Distributed cluster is formed to guarantee data delivery and life-time improvement.
SPIN	1	Movable	Exchange metadata to reduce number of messages **and** lifetime.
REAR	> 1	Restricted	Lifetime extend**ed** and data delivery ensured.
Energy aware	> 1	Restricted	Lifetime extend**ed**
Direct diffusion	> 1	Restricted	It establishes efficient n-way communication paths for fault tolerance
Information driven	1	Restricted	It saves more energy using optimization of direct diffusion techniques
Gradient	1	Restricted	It delivers data through the minimal number of hops
PEGASIS	1	Stable base station	It is lifetime with bandwidth optimization
Energy-aware based cluster head	1	Not at all	It is lifetime and operate in a real-time
Self-organized	1	Movable	It improves fault tolerance
Minimum energy comm. Net.	1	Not at all	It is lifetime and self-reconfiguration
Geographic Adaptive Fidelity	>1	Restricted	It increases the network lifetime as number of node increases

Smart Embedded Wireless Technology System Architecture

The (IoT) is a widespread network technology that allow billions of things, devices, and human in a network for resources sharing and communication over the 6LowPAN platform using internet of thing protocol version 6 (IPv6) addresses. The embedded wireless system-based internet of things (EWS-IoT) architecture includes integration of different technologies, facilities and services (such as embedded system (ES), network technology (NT) and information technology (IT).

Embedded Technology

Embedded technology is a subset of IoTs that provide services like software program, device drivers and firmware to the industrial products such as automobile, electronics, industrial control system, biometrics system, healthcare devices, digital signal processing devices and networking devices. The effectiveness of this system services in the IoT architecture may include microchip, gateway, sensor/mote, GSM module and others to render functions like quality of services, end-to-end communication, and interoperability.

Network Technology

Network technology is also a subset of IoTs that helps to provide end-to-end connectivity with the use of wired or wireless technology and protocols. The role of this technology is to allow a seamlessly sharing of resources, information and application program over the World Wide Web (WWW) or internet. This network service may utilize the build infrastructure to relay information to the cloud database through information system, internet, voice calls, GSM/SMS. Many other attached wireless technologies are Bluetooth Low Energy (BLE), ZigBee, Z-wave, RFID, Wi-Fi, 6LowPAN and so on, which their operations depend on power.

Information Technology

Information technology (IT) in the IoTs platform is a subset of information and communication technology which described application of computing, processing, storage, retrieving, and manipulation of information on the internet. This IT service includes mobile web application, programming and cloud database system. The embedded wireless system facilities involved in the internet of thing architecture is illustrated in Figure 4.

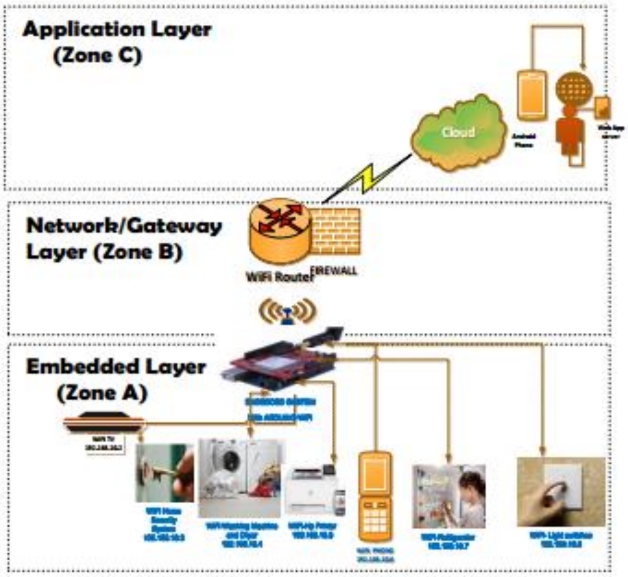

Figure 4. Embedded wireless system based-IoTs architecture.

Abstract Model for Embedded Wireless System Based IoT Design

The integration of several facilities involved in the SEWS-IoTs architecture are represented by a state in abstract of Markov chain which introduces randomness model. The transitions among the states are strictly limited to transitions from the state with higher priority to the nearest state of lower priority, unless a precise match of analyzed binary vector is identified at point where the system returns to the state with the highest priority. The priority assigned by order of vector groups in the IoT model is from leftmost element of each codebook which has highest priority and the rightmost elements having the lowest priority as shown in Figure 5. Therefore, the composition of facilities functions in the IoTs architecture can be given as;

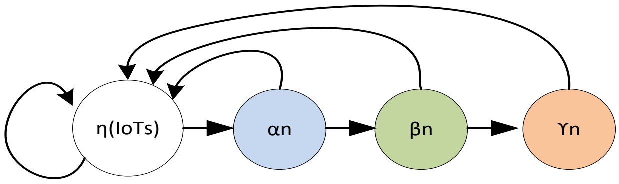

Figure 5. Abstract model of embedded wireless system based-IoTs

$$\eta = \{\alpha_1, \beta_1, \gamma_1 \ldots\} \quad (14)$$

$$\alpha_1 = (\alpha_{11}, \alpha_{12}, \alpha_{13} \ldots \alpha_n) \quad (15)$$

$$\beta_1 = (\beta_{21}, \beta_{22}, \beta_{23} \ldots \beta_n) \quad (16)$$

$$\gamma_1 = (\gamma_{31}, \gamma_{32}, \gamma_{33} \cdots \gamma_{3n}) \quad (17)$$

$$\eta = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \ldots \alpha_{1n} \\ \beta_{21} & \beta_{22} & \beta_{23} \ldots \beta_{2n} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \cdots \gamma_{3n} \end{pmatrix} \quad (18)$$

where: η is IoTs architecture, α is an embedded technology component, β is network technology and γ is information technology services in IoTs models.

IoT Communication Model and Design

The communication model of IoT depends on the protocol handler which utilized transport control protocol-internet protocol (TCP-IP) for end-to-end communication and encapsulation of data from local area network to the remote interfaces. The communication protocol of low-level firmware implementation is targeting to function over a wide area network connectivity due to the gateway connection between the cloud database and remote server using wireless access point (WAP) and wireless gateway support-node (WGSN). In the process, the dynamic session renegotiations (DSRs), Forced-session-renegotiations (FSRs) on the internet gateway and content management system server (CMSS) are to significantly improve the sensor nodes connectivity over the internet and reduced packet loss rates among the sensor nodes.

The DSR is function in two ways, for exchange packet transmission and verifying status of both gateway and CMS server channel (either is in uplink and downlink status). The DSR also verify the appearance of socket failure or deadlock of a packet sent between the clients and servers. If the data packets are unable to deliver or received from TCP/IP connection, the FSR procedure will setup to check available packet or data received from gateway unit for a period of elapsed time. This process will cause CMSS to wait for a new renegotiation or reconnection between the client, server and closed TCP/IP socket. But, if network service or packet lost during the transmission and communication setup between gateway and CMSS, the TCP/IP will attempt a reconnection until connection establishment is successful.

The involvement of this different application layer protocols and programming language design used for the communication between IoTs gateway and cloud database in the architecture (e.g JNL, micro C, MySQL and protocols like CoAP and HTTP etc) can be expressed as follows.

$$\varphi_G = \{N_1, N_2, N_3, \ldots, N_z\} \quad \textbf{(19)}$$

$$N_1(\varepsilon) = \{N_{11}, N_{12} N_{13} \ldots, N_{1i}\}' \quad \textbf{(20)}$$

$$N_2(\varepsilon) = \{N_{21}, N_{22}, N_{23}, \ldots, N_{2i}\}' \quad \textbf{(21)}$$

$$Cache = \{x_1 N_1 + x_2 N_2 + x_3 N_3 \ldots, x_n N_{zm}\} \quad \textbf{(22)}$$

Simulation of IoT Communication Model

The communication model of IoT architecture was developed and simulated using cooja-contiki WSN software. The CoAP web services with RESTful HTTP was adopted as an interoperable application level protocol. These protocols focus on end-to-end communication, and interoperability achievement among things (nodes) connected in a network.

Cooja-contiki is a flexible java-based simulator that supports C language for application software development in Java Native Interface (JNI). It allows both large and small networks of sensor motes to be simulated and implemented with different conditions and system settings like packet rates generation, media access control protocols (MAC), throughput, packet loss and network topology. This network design consists of four sensor motes which running CoAP servers as resources constrained protocol, and they are periodically queried by the CoAP client using Californium based Java program. The GET requests command is sent to the servers in the simulation environment to obtain the values through the border router, and help to connect the network with internet using the Contiki-tunslip utility as illustrated in Figure 6.

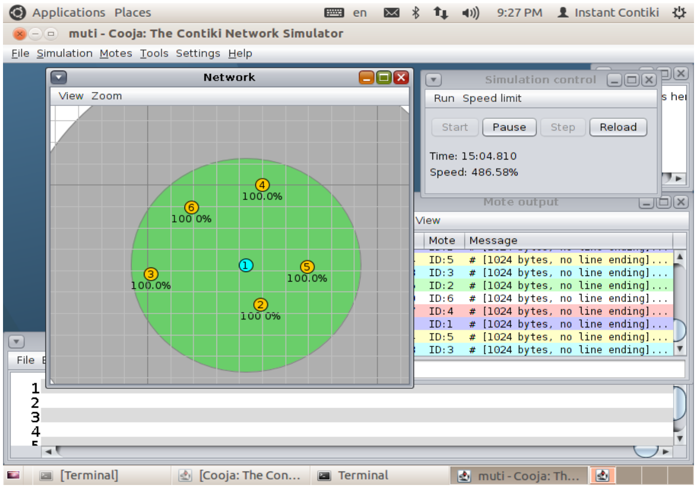

Figure 6. Cooja-contiki GUI simulation environment.

Simulation Results of Communication Model Based-IoT and Analysis

The communication of this wireless sensor nodes simulation results shows the accuracy and efficiency of the packet transmitted from the field (physical layer) to the clouds database system. The result of packet generation (packet/sec), packet loss against throughput during packet transmission are presented in Table 3 and Table 4 respectively. Figure 7 and Figure 8 depicts graphs of packet generation, packet loss against throughput. While Figure 9 and Figure 10 shows the average packet delay and average period of packet transmit during end-to-end communication node in the simulation environment.

Table 4. Simulation results of packet rate generation against throughput

PGR (packet /sec)	***Network Throughput (Kb/s)***			
	Sensor Node1	Sensor Node2	Sensor Node3	Sensor Node4
1	0.915	0.8757	0.7254	0.6505

5	1.2714	0.9932	0.7792	0.6566
10	1.9454	1.3552	1.1732	1.8463
15	2.122	1.4545	1.1921	1.2571
20	2.2748	1.9837	1.3534	1.5462

Table 5. Simulation results of packet rate generation against packet loss

PGR (packet/sec)	***Packet loss (%)***			
	Sensor Node1	Sensor Node2	Sensor Node3	Sensor Node4
1	1.20	2.70	4.55	5.50
5	3.90	5.71	8.55	11.61
10	5.25	7.02	12.25	21.77
15	6.42	7.05	13.45	14.55
20	7.51	9.21	14.6	17.05

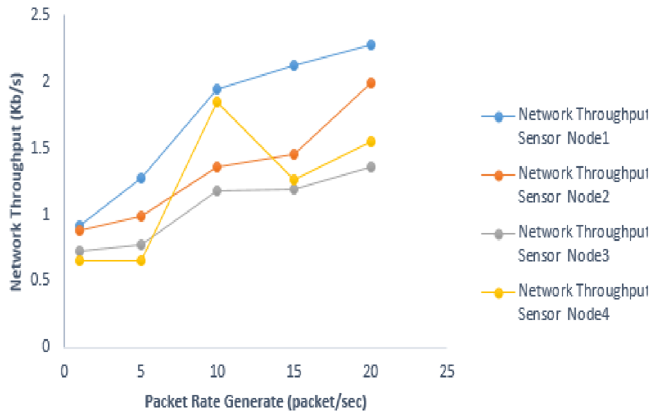

Figure 7. Graph of network throughput against packet generate rate.

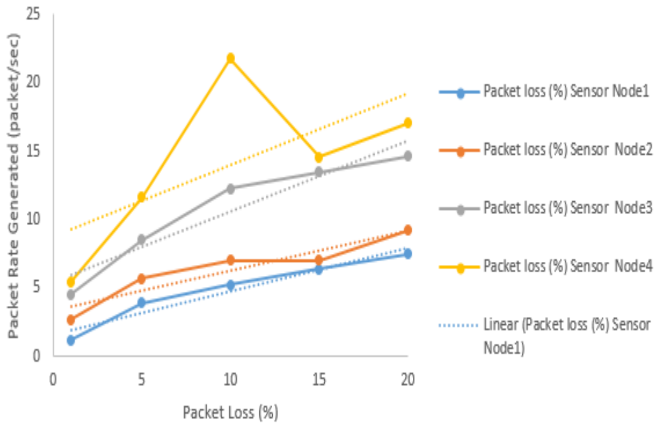

Figure 8. Graph of packet generate rate against packet loss.

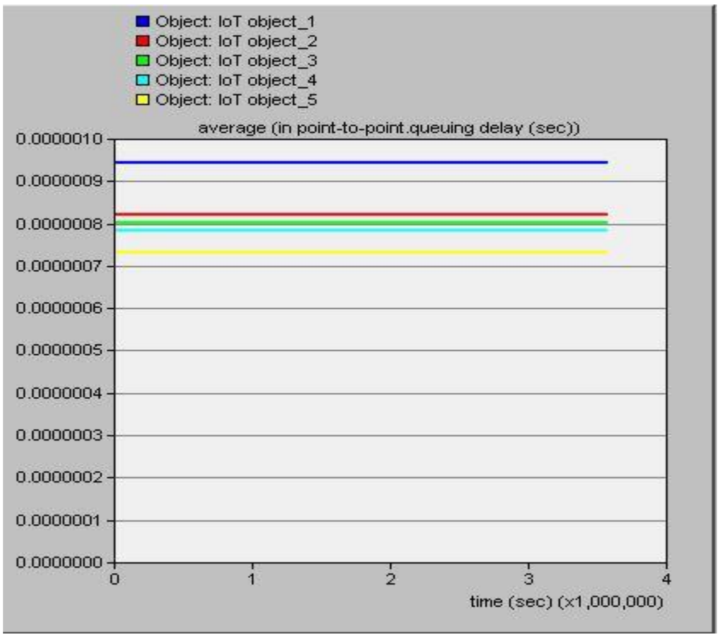

Figure 9. Graph of average packet delay of sensor nodes in point-to point.

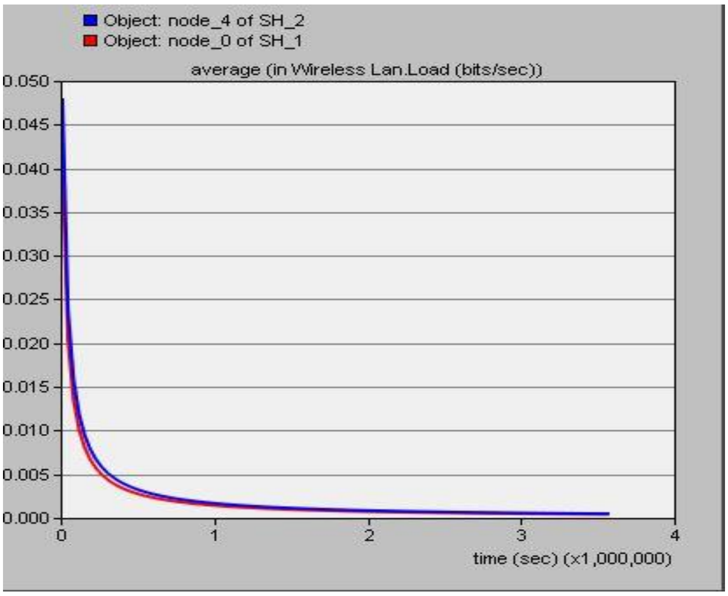

Figure 10. Graph of average period/packet transmit (bits/sec).

Conclusion

This research investigation, analyzed the selected operational factors for embedded wireless system based-IoT constraints. They are choice of routing technique, nature of transmission media, topology, network models, IoT architecture/communication model, data model constraints, operating environment and relevant performance indicators. In this research, the survey shows that energy consumption pattern, fault tolerance, reliability and scalability affecting the optimal performance of EWS-IoT design. The research also gives a clear and cohesive description of the proposed IoT design model together with the pertinent systemic components. The design requirements and technical procedures of integrating embedded devices, sensor networks and wireless data communication for the enhancement of the proposed IoT architectural model is also elucidated in this research work. The proposed of the efficient design of this embedded wireless system depends on hardware design, software coding and control theory with holistic approach of computation to suit physical environmental constraints. The aforementioned operational factors and performance indicators were comprehensively explained and supported with analytical definitions, mathematical equations, descriptive figures and table of performance comparisons. These technical explanations are systematically provided in order to highlight the relevant design considerations for realizing an efficient IoT-based smart embedded wireless system. In order to validate and verify the proposed design, the end-to-end communication simulation performance metrics was measured using packet generation rate, packet loss rate, throughput, and packet delay.

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