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Research Article

Traffic Balancing Network Architecture for Enhancing Lifetime of Smart Devices in Low Power Internet of Things Networks

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Abstract: The aim of our study is to integrate the features of node placement technique and routing technique in single network architecture to enhance the lifetime of low power IoT Networks. The Internet of Things (IoT) is smart technology that converges smart devices with global network infrastructure and promotes effective resource utilization. Smart devices are considered as key element in low power IoT networks (energy constrained IoT network infrastructure). The phrase "low power" refers the battery sourced IoT devices and low power radio links (IEEE 802.15.4). Enhancing the lifetime of smart devices by balanced energy utilization is the major goal in low power IoT networks. Thus, we propose energy efficient and reliable network architecture by integrating the features of node placement technique and routing technique. In proposed network architecture, traffic load is concentrated, since traffic load decidedly influence the energy efficiency and reliability of the network. In node placement technique, transmission ranges of nodes are varied based on data traffic, which assures balanced energy utilization and maintains network connectivity. Traffic load information is added in routing process, to achieve reliable data transfer and to balance energy utilization. Thus, effective integration of routing technique and node placement technique in single network architecture highly promotes the network lifetime with better reliability. The idea at the heels of our work is integrating features of two optimization techniques in single network architecture will satisfy specific network requirements. From our results, it is observed that the proposed network architecture prolongs the network lifetime and maintains reliable data transfer.

Keywords: Energy efficiency, internet of things, network architecture, node placement technique, reliability, routing technique, traffic load

INTRODUCTION

Internet of Things is a (sensor/actuator, RFID, Bio-chip, etc) is a rising innovation, that is practiced in private as well as public sectors. The major reason behind of IoT development is low power radio protocol design and MEMS technology (technology that is used to develop low power and low-cost device). Providing effective communication between low power devices with the aid of low power radio links in energy constraint network environment is the prime challenge in IoT research field. In environmental monitoring applications as well as commercial applications, frequent battery replacement and un-reliable communication severely affects the service provider as well as customer (Lee *et al*., 2012). The general components of IoT design is depicted in IoT world forum reference model, which was introduced by CISCO in its white paper and we included the challenges of every layers. Figure 1 describes IoT world forum reference model, it is seven layered architecture models. In lower layers, real time data aggregation and processing is done. In higher layers query based data aggregation and processing is done. Middle layer is called data accumulation layer, which is used to store the data that is generated by other layers. First three layers holds edge devices, which collects real-time data and they are connected by low power radio links (IEEE 802.15.4, IEEE 802.11), which are unstable and highly lossy in nature (Vasseur and Dunkels, 2010).

Since, it is observed that IoT is highly constrained by energy (Perkins *et al*., 2003), therefore we are concentrating in challenges of lower layers. The major factor that affects the energy efficiency and reliability is unbalanced data traffic, which leads to node overload (energy hole), thus traffic load is concentrated in proposed network architecture.

From the characteristic features of IoT network, it is observed that energy efficiency and reliability are the

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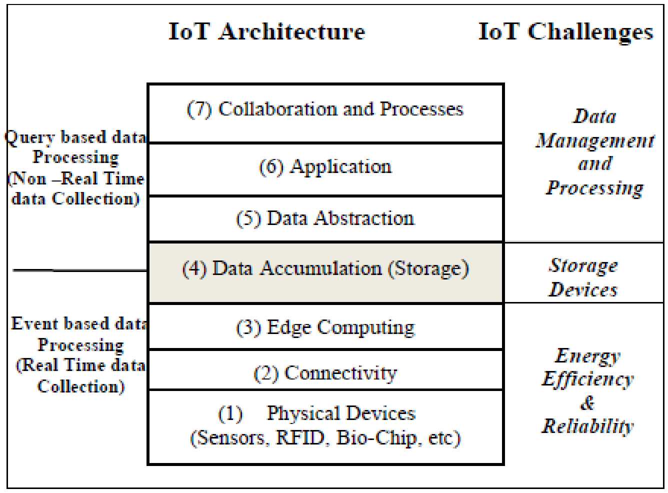

Fig. 1: IoT world forum reference model

major objectives in low power IoT networks. In low power wireless networks, communication unit plays the key role, the energy consumed by communication unit of the devices is 70% to 80% (Boukerche, 2009). Regulating communication unit in efficient way highly improves the network performance. Thus, by integrating the features of node placement technique and routing technique communication unit is effectively regulated in the proposed network architecture. Node placement technique is implemented in network setup phase and routing technique are implemented in network initialization phase. In node placement technique, transmission range of nodes varied based on the traffic area. In routing mechanism, traffic load information included to compute energy efficient and reliable path. Hence effective integrating of two different techniques (variable transmission ranges and traffic load based routing) avoids energy hole and maintains reliable data transfer.

LITERATURE REVIEW

Relay node placement: Many literatures describe placing relay node in network scenario, highly improves network performance. Bari (2005) made a efficient survey about relay node placement technique, in his survey he described that, efficient relay node placement in wireless sensor networks, maintains network connectivity and improves the network lifetime. Dasgupta *et al*. (2003) described the features of relay nodes in low power networks, authors describe that effective relay node placement improves network lifetime and improves network connectivity.

Node density variations: Yun and Xia (2013) elaborated the energy hole issue and found the efficient solution to avoid energy hole issue, authors of this study describe that, node density variation in network scenario avoids energy hole issue. Wu *et al*. (2008) introduced a node placement technique by using non-uniform node density mechanism, In this study, authors varied the density of nodes based on corona of network, they describe that node density variations prevents energy hole issue. Jia *et al*. (2013) proposed theoretical rational for relay node density, they say varying the density of nodes improves the energy efficiency of the network. Varying node density based on traffic are highly improves the network lifetime.

Transmission range variation: Instead of varying the density of nodes based on traffic area, varying the transmission range of nodes can also balance the energy consumption of network and also it reduces the density of nodes in the network. Bein *et al*. (2009) introduced three different distributed algorithms that varies the transmission range of nodes based on network requirements. This study describes that varying the transmission range improves the energy efficiency of the network. Yu *et al*. (2011) analysed non-uniform maximum transmission range for wireless networks and proposed Non-Uniform Maximum Transmission range (ENMT), In this study the transmission range of nodes are varied with respect to data traffic, to obtain suitable transmission range for every sensor node in the network. Zhao *et al*. (2008) introduced variable transmission range adjustment scheme based on quality coverage (EBVTC), they explained that EBVTC highly reduces the non-uniform energy consumption. From the literature, it is understood that effective node placement by using relay nodes and varying the transmissions range of nodes in network highly balances the energy consumption and prolongs the network lifetime.

Routing mechanism: Routing is one of the well know technique to improve the network performance. AODV (adhoc on demand distance vector) is one of the efficient routing protocol among standardize routing

Table 1: AODV extensions

Authors	Year	AODV Extensions	Routing metric	Features
Perkins *et al*.	2003	AODV	Hop-Count	Finds shortest paths
Lee and Gerla	2000	AODV-BR	Hop-Count	Maintains backup routes
Marina and Das	2001	AOMDV	Hop-Count	Multiple loop free paths
Crisostomo *et al*.	2004	AODV-PLRR	Hop-Count	Routing based on link stability
Kim *et al*.	2005	EAODV	Hop-Count	Selective route cache concept
Tauchi *et al*.	2005	AODV-BA	RSS, battery level	Predicts link failure
Rehman and Wolf	2007	AODV-AP	Signal Strength	Finds accessible routes
Liu *et al*.	2008	MMRE-AOMDV	Residual Energy	Routing based on RE
Sambasivam *et al*.	2004	MP-AOMDV	Signal Strength	Adaptive multipath routing
Proposed Work --------------> Traffic load information is included that ensures better reliability and energy efficiency				

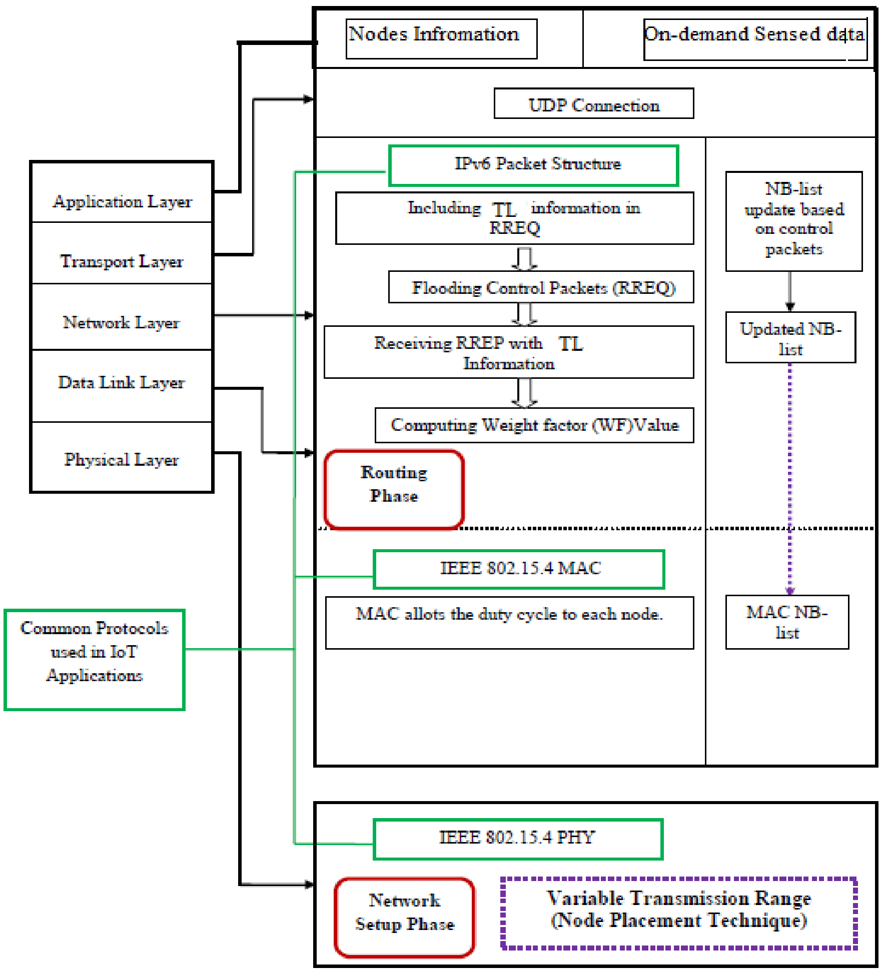

Fig. 2: Blue print of proposed cross layer model

protocols. AODV is more suitable for low power wireless network environment. Hence extended version of AODV is used in proposed network architecture. Perkins *et al*. (2003) proposed AODV routing protocol, later various extensions of AODV protocol is proposed to satisfy specific network requirements. Table 1 describes the extensions of AODV routing protocol and its features.

Motivation: Many cross layer research works such as EQSR (Ben-Othman and Yahya, 2010), XPL (Vuran and Akyildiz, 2010), Breath (Park *et al*., 2011; Huang *et al*., 2010) describes that integrating two different layers effectively promotes network performance. Based on this observation, a literature study is carried out on node placement techniques and routing technique. From our study, we understood that varying the transmission range of nodes in network balances the data traffic and performs better in energy utilization. Similarly, including effective parameters in routing technique achieves required network objectives. Therefore, our idea is to utilize the features of these two techniques in single network architecture to enhance the network performance.

MATERIALS AND METHODS

Network model: In proposed network architecture, basic assumptions are made in our network scenario. Relay and sensor nodes are stationary, transmission range of relay nodes are varied based on traffic area, nodes are aware of the TL information, sensors and relay nodes are limited by energy, Sink is not limited by energy. Real time IoT network is designed by sensor devices (temperature sensor, pressure sensor, bio-sensor, RFID tag, etc.), data acquisition boards and base station nodes. To adopt real-time IoT scenario in our network model, we consider data acquisition boards as relay nodes and sensor devices as sensor nodes. Figure 2 describes the blue print of proposed network architecture.

Energy model: Every wireless network adopts particular energy consumption model or dissipation model. In proposed work, we adopt first order radio model. The energy required to transmit k-bit message (data unit) at a unit distance d is defined as:

$$Etx\ (k, d) = \mu + \delta\ d^{x} \quad (1)$$

μ is the energy consumed by transceiver circuit, δ is the energy consumed by transmitter amplifier to transmit k bit message and x is the path loss exponent, Similarly the energy required to run the receiver circuit is defined as:

$$Erx\ (k) = \mu \quad (2)$$

where,
μ is the energy consumed by transceiver circuit

Theoretical description for proposed node placement technique: The network scenario is assumed as disk shape. The whole disk is divided into various rings. From Gupta and Kumar (1998) coverage and connectivity mechanism are adopted, which ensures the connectivity of the network. Data traffic, energy consumption and transmission range of proposed architecture is derived for particular ring I (based on distance from base station), which can be adopted by all other rings.

Notations:

h : Total number of rings
Ri : Ring i, $0 \le i \le h$
Ai : Area of ring i
ρi : Node density of ring i, $1 \le i \le h$
Ni : Number of the nodes in the ring i, $1 \le i \le h$
Ti : Amount of data traffic in ring i, $1 \le i \le h$
Ei : Energy consumption in ring i, $1 \le i \le h$
Ci : Cost of the node in ring i, $1 \le i \le h$
γi : Communication range of node in ring i, $1 \le i \le h$

Number of nodes in a particular ring (ring i) is defined as:

$$Ni = Ai\ .\ \rho i \quad (3)$$

Therefore, it can be written as:

$$Ni = \Pi\ (2i\text{-}1)w2\ .\ \rho i \quad (4)$$

From Eq. (1) and (2) amount of data traffic in the traffic are i can be defined as:

$$Ti = Ni\ (k) + \sum_{s=i+1}^{h} Ns\ (k) \quad (5)$$

In the Eq. (3) "k" is defined as number of bits (unit message), Ni(k) refers to the number of bits:

$$T1 = N1\ (k) + \sum_{s=2}^{h} Ns\ (k) \ldots Ti = Ni\ (k) + \sum_{s=i+1}^{h} Ns\ (k) \ldots\ldots\ldots Th = Nh\ (k) \quad (6)$$

Generated by the nodes present in ring Ri, Ns(k) refers to the number of bits forwarded from "i+1"ring to "h" ring. From (5), the data traffic from first ring to last ring can be defined as, Eq. (6) describes that, data traffic in a network increases from outer ring to inner ring (towards the base station):

$$T1 > T2 > T3 > \ldots\ldots Ti > Ti+1 > \ldots\ldots Th \quad (7)$$

Equation (7) describes that, in any kind of flat based network architecture, as the distance increases the traffic decreases. Similar to data traffic energy required to transmit the data in the ring "Ri" can be written as:

$$Eci\ (Tx) = [k\ (\mu + \delta\ dx)]\ Ni + \sum_{s=i+1}^{h}[k\ (\mu + \delta\ d^{x\ Ns} \quad (8)$$

Energy required to receive the data, from ring "Ri+1" to "Rh" can be written as:

$$Eci\ (Rx) = \sum_{s=i+1}^{h}[k\ (\mu)]\ Ns \quad (9)$$

Total energy consumed at the ring Ri can be written as:

$$Eci(Total) = [k\ (\mu + \delta\ dx)]\ Ni + \sum_{s=i+1}^{h}[k\ (\mu + \delta\ d^{x\ Ns}{}_{+\ s=i+1hk}\mu^{Ns} \quad (10)$$

Similarly, energy consumed at ring h can be written as:

$$Ech(Total) = [k\ (\mu + \delta\ dx)]\ Nh \quad (11)$$

From Eq. (10) and (11) it is noticed that energy utilization from ring Rh to ring Ri, decidedly increases. Similarly, energy consumption from ring Ri to ring R1 also increases:

$$Ec1 > Ec2 > Ec3 > \ldots\ldots Eci > \ldots\ldots Ech \quad (12)$$

From Eq. (7) and (11) it is seen that energy consumption and data traffic increases from ring Rh to R1 (outer ring to inner ring). It describes that nodes nearer to the sink carries huge data traffic and consumes more energy. Based on this observation, we conclude that increasing the density of the node towards base station balances data traffic and energy consumption:

$$N1 > N2 > N3 > \ldots\ldots > Ni > \ldots\ldots > Nh \quad (13)$$

From Eq. (1) and (13) node density can be increased as:

$$\rho 1 > \rho 2 > \rho 3 \ldots\ldots > \rho i > \ldots\ldots\ldots > \rho h \quad (14)$$

The limitations in increasing node density is that, as the node density increases, implementation cost as well as control packed overhead increases.

Thus, transmission range of nodes are varied with respect to traffic area. Γ is assumed as communication range of node. γ is directly proportional to transmission power (Pt) and reception power (Pr) in the network. When γ increases, Pr and Pt increases:

$$\gamma = Pt \times Pt \quad (15)$$

To balance the energy consumption in network, γ need to be reduced for nodes, which holds huge data traffic. Hence for traffic T1 > T2 > T3 > ………..Ti > Ti+1 >………..Th, in rings R1, R2 …Ri…Rh, the communication range can be varied as $\gamma_1<\gamma_2<\gamma_3<\ldots\ldots\gamma_i<\gamma_{i+1}\ldots\ldots<\gamma_h$. Hence from above relation it is seen that varying the communication range based on data traffic highly balances the energy consumption as well as it reduces control over head.

Varying transmission ranges: Transmission ranges of nodes can be varied are by varying the RX threshold (the minimum receive signal level the link will work with) and CS threshold (carrier sensing range of the node to sense the sender's transmission) values (Jung and Vaidya, 2002). Transmission range of nodes are adjusted based on following assumptions.

Rmin (CS and RX min power level) ≤ R (Adjusted transmission range) ≤ Rmax (CS and RX max power level).

Rmin is the minimum transmission range of node, R is the adjusted transmission range. To ensures better connectivity the following condition need to be satisfied, 2 Rc (communication range) >Rs (Sensing range). In our network model, to ensure network connectivity, the transmission range for nodes present ring i is kept equal to width Wi. Width of ring i, it is defined as wi (meters) = ai+1 (radius) -ai (radius). Figure 3 describes the proposed node placement technique with variable transmission range.

Routing mechanism: In proposed routing mechanism, AODV routing protocol is used. AODV is a reactive protocol, which performs better in bandwidth utilization. In the proposed work, traffic Load Information (TL) are incorporated in existing AODV protocol, to ensure reliability of the network.

Traffic load: Node with limited buffer size drops the approaching data packets, when incoming packets surpasses queue size that is referred as congestion. In flat based networks, increasing congestion leads to re-transmissions. Huge node over-burden and more number of re-transmission severely disturbs the reliability and energy efficiency of the network. Traffic load (Farooq and Jung, 2013) for a node can be computed by measuring the time interval between two received data packets (old packet interval and new packet interval). In routing mechanism, traffic load value is scaled from can be scaled from 0 to 1, 1 can be considered as minimum traffic load. Traffic load for a node can be defined as:

$$TL = (1-\beta) \times \text{old interval} + \beta \times \text{new interval} \quad (16)$$

Equation (16) is used to calculate the traffic load (TL) for route discovery process, to include TL in

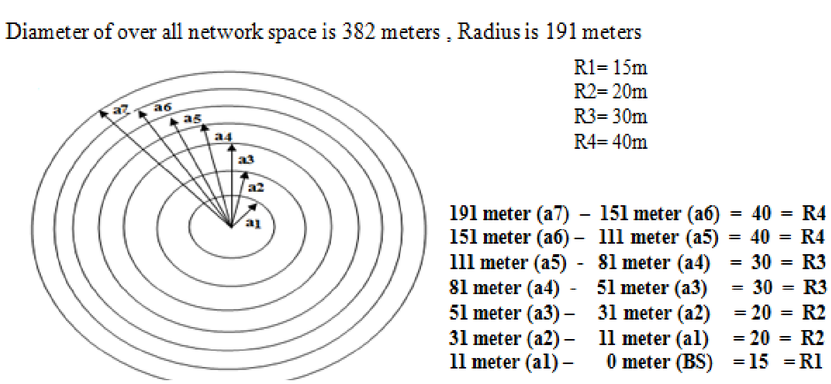

Fig. 3: Transmission range variation

Type	Flags	Reserved	Hop count
RREQ (broadcast) ID			
Destination IP Address			
Destination Sequence Number			
Original IP Address			
Original Sequence number			
Traffic Load			

Fig. 4: Control packet structure

AODV routing process; it should be added in RREQ (Route Request) control packet of AODV protocol. By adding TL should be included in RREQ packet, path with less TL can be computed to ensure reliable data transfer. Figure 4 describes the control packet structure and route discovery process of destination node.

RESULTS AND DISCUSSION

In this study, Network Simulator- 2 (NS 2.34) is used to evaluate the performance of proposed node placement scheme and routing mechanism. Table 2 describes simulation setup.

Table 2: Simulation setup

Routing protocol	AODV, AODV (TL)
MAC layer/ physical layer	IEEE 802.15.4
Channel type	Wireless
Radio propagation model	Two ray ground
Traffic type	Constant bit rate
Antenna model	Omni directional
Initial energy (Sensors)	50 joules
Initial energy (Relays)	60 joules
Total number of nodes	200 (50-relay) (150-sensors)

Network lifetime: Network lifetime is estimated based on first node drain out, when the first node drains out its power, the remaining nodes drain outs its power with in short span of time. In our simulation, we compared the performance of proposed network architecture with standard model (IEEE 802.15.4 and AODV). EQSR is considered as one of the standard cross layer routing protocol thus we compared our proposed architecture with standard protocol and EQSR protocol.

Figure 5 and 6 and Table 3 represents the network lifetime estimation of network scenario 1, 2 3, 4, 5. Network lifetime is estimated based on first node death, since if one node run out its power, with in short span of time every node loose its energy. In network scenario 1 - standard model (IEEE 802.15.4 and AODV), first node death occurs at 303 seconds and only 8 nodes survived for whole simulation period. In network scenario 2 - EQSR protocol, first node death occurs at 601 seconds and 22 nodes survived for whole simulation period. In network scenario 3- Implementation of node placement technique alone (not including routing technique), first node death occurs at 405 sec and 20 nodes survived for whole simulation period. In network scenario 4 - Implementation of routing technique alone (not including node placement technique), occurs at 509 seconds and 25 nodes survived for whole simulation period. In network scenario 5 - proposed first node death architecture (integration of routing and node placement technique), first node death occurs at 891 sec and 30 nodes survived for whole simulation period. From this observation, we can say that proposed network

Average energy consumption: The energy utilization of the network is measured based on average energy consumption of nodes. In proposed network architecture data traffic is balanced by node placement technique and energy efficient and reliable path is computed by the aid of routing technique, thus proposed network architecture achieves balanced energy utilization.

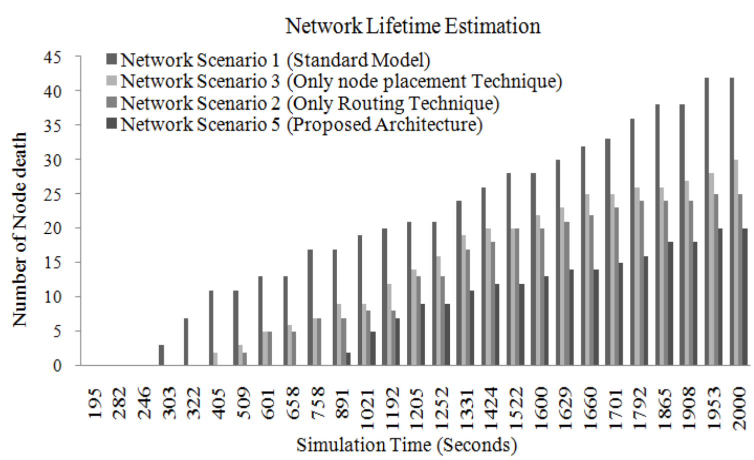

Fig. 5: Network lifetime estimation

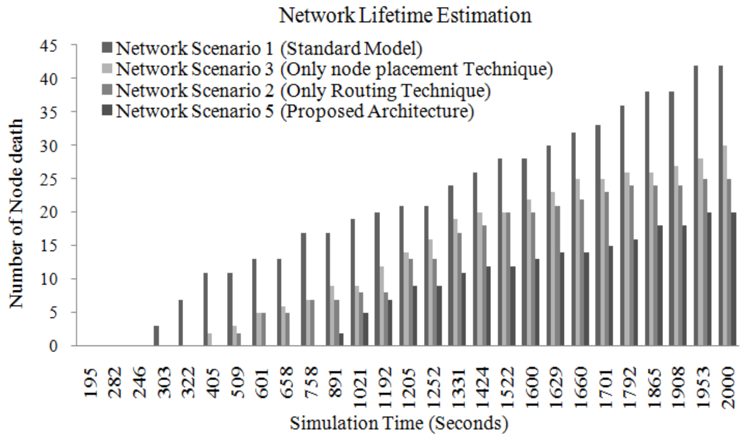

Fig. 6: Network lifetime estimation

Table 3: Network lifetime estimation

Protocols	Standard	EQSR	Implementation of Node Placement	Implementation of Routing	ETRT-model
First node death	303 seconds	601 seconds	405 seconds	509 seconds	891 seconds
Average node death	21	14	14	12	8
Nodes survived	8	22	20	15	30
500 sec (node death)	11	0	2	0	0
1000 sec (node death)	19	10	17	9	5
1500 sec (node death)	28	19	20	20	12
2000 sec (node death)	42	28	30	25	20

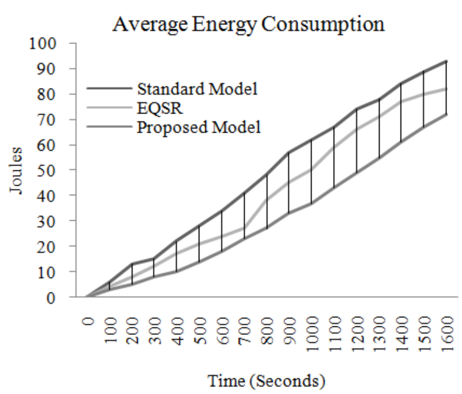

Fig. 7: Average energy consumption

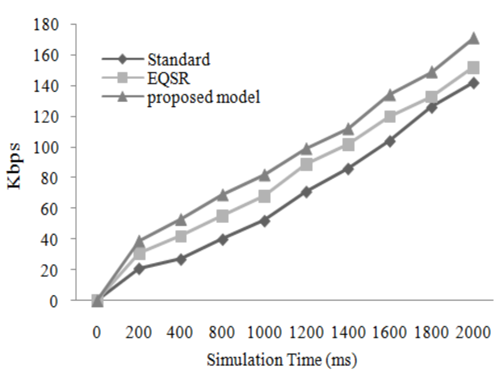

Fig. 8: Throughput comparisons

From Fig. 7, it is observed that, proposed network architecture balances the energy in efficient way.

Throughput: In our network architecture traffic load information of every node is included in routing process, which maintains reliable route. From Fig. 8, it is observed that proposed architecture gives better throughput value when compared to the standard model and EQSR protocol. From the above results, it is noticed that proposed network architecture is energy efficient and reliable in nature.

CONCLUSION

Internet of Things is to a great degree received by numerous applications. IoT innovation is great for private as well as open organizations. IoT network is alluded as low power remote system, since it is operated by battery sourced devices and low power radio connections. Achieving better network lifetime in energy constrained network environment is the major challenge in IoT networks. Network lifetime can be improved by effective energy utilization and reliable data transmission. Based on these observations energy utilization is balanced by node placement technique and reliable data transfer is achieved by routing technique. In node placement technique, the data traffic is regulated by varying the transmission range of nodes with respective to data traffic. In the routing technique, reliable and energy efficient path is computed based on Traffic Load (TL) value. Hence, utilizing the features of routing mechanism and node placement technique in unified network architecture improves the network lifetime with better reliability. Our simulation results show that the proposed network architecture is energy efficient and reliable in nature, which can be a suitable network architecture for energy constrained IoT networks.

In proposed network architecture, we persuade that integrating the features of two optimization techniques in single network architecture satisfies specific network requirements. For future work, QoS based network architecture can be designed by integrating the features of MAC layer, network layer and TCP/IP layer.

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