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BLE in IoT: Improved link stability and energy conservation using fuzzy approach for smart homes automation

Kothandaraman D. [a,*], A. Harshavardhan [a], V. Manoj Kumar [b], D. Sunitha [c], Seena Naik Korra [a]

[a] School of Computer Science and Artificial Intelligence, S R University, Warangal, TS, India
[b] Department of Computer Science and Engineering, S R Engineering College, Warangal, TS, India
[c] Department of Computer Science and Engineering, KITS, Karimnagar, TS, India

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ABSTRACT

Internet of Things (IoT) the studies home automation and creating homes smarter over IoT wireless technologies that link stability and energy efficiency with makes the wireless protocol perfect for use in IoT. Bluetooth-Low-Energy (BLE) has a high possibility to becoming a significant technology for the IoT in low power, low cost and compact devices. Further it can used to decrease the energy-consumption of BLE. This research work proposes a fuzzy logic based method to determine the links stability of nodes position with velocity and sleeping time of home IoT-devices automation using BLE technology. Sleeping time of IoT-devices reduces has battery level and Throughput and Workload (T/W). The present system results has been evaluated using fuzzy logic with triangular membership functions and showed better performance when compared with existing home automation.

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1. Introduction

IoT is a network form of communication between people and things, things to things and things itself. Each of the things or objects it's communicated with the other people and plays a defined role [1]. IoT-wireless network based BLE technology has become progressively widespread through the past years [2,3]. IoT in the field of smart home environment acts as actuators Bluetooth Low Energy (BLE): a small bursts of data, impressive battery life, low cost, works on free of cost 2.4 GHz band and ideal for sensors-IoT [1].

Typically, Home Automation (HA) protocols a indoor/centralized master BLE control of home-appliances, such as lighting, security systems air-conditioners etc., [1]. Such HA system is inappropriate in IoT with dynamic network topology.

Compares dynamic Low power wireless technology supported in IoT devices [1,4] such as BLE, A(ANT), A+(ANT) ZigBee, WiFi, Ni (Nike+), Ir(IrDA) and Near Field Communication (NFC) standard [5]. Here BLE based fuzzy logic is focused aiming energy conserving of the network to improve link stability.

1.1. Motivation

To provide secure and energy efficient smart home automation. To achieve dynamic multi-hop communication system using BLE. Fig. 1 represents the motivation of the paper [5]. Smart phones are increased to thousand since 2013 and 9000 up to 2020. X- axis represent the BLE technology increased in terms of year wise and Y-axis represent increased smart phones in terms millions.

1.2. Issues and challenges

In this paper following issues and challenges are faced: device discovery delay, link stability and limited resources include energy and bandwidth [6,7].

2. Related works

In the related works, transmissions among mobile-devices are done maintained through central controls which are commonly denoted as wireless network. It is self-organized in an ad-hoc mode, where terminals themselves are can do connections with each other and transmit using multi-hop mode without aid of third party [8,9].

* Corresponding author.
E-mail address: d.kothandaraman@sru.edu.in (Kothandaraman D.).

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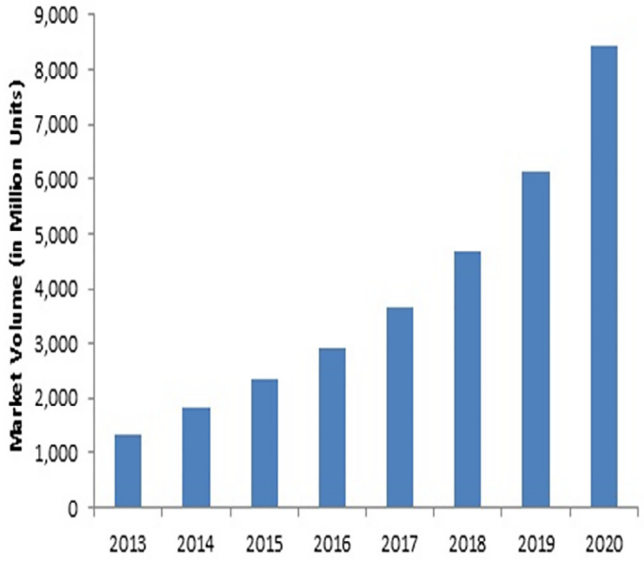

Fig. 1. Increased BLE technology in market.

Transmission is important swapping information between one and many people from any-where at any time. BLE-IoT is cluster of smart-mobile nodes which form an autonomous network for any centralized management. Yet smart-mobile devices enhancing its battery life-time is an important intention. Furthermost of the investigators recently considered energy-aware routing protocols for IoT. Since each smart-mobile node in an IoT achieves the routing for creating transmission among different smart-mobile nodes. Even a few of the nodes are dead due to energy tiredness which might cause disconnecting of the whole IoT networks.

IoT nodes operation is battery based and it has limited energy level of nodes. Since the nodes have mobility that out of radio coverage range; it may causes communication links failure frequently [12,13]. So there are two problem observed related to this network such as node dying of energy tiredness and out of radio coverage area [14].

In this paper, various IoT enabled wireless technology vs IoT network topology are compared and are shown in the Table 1. Table 2 represents comparison between wireless technologies vs power efficiency of different communication technologies. Table 3 represents the wireless technologies ranges support. Table 4 represents the throughput of different technologies.

IoT routing in wireless networks faces problem in discovering route and sustaining towards destination through movement and moving topologies [10,11]. For this an algorithm which guarantees robust connectivity and limited node range has been proposed. In [15,16], link stability routing algorithm has been developed for creating and sustaining efficient routing in smart home automation using BLE for IoT.

3. Proposed system

The impartial of the proposed method is to improve the link stability, improve network life time, to increase throughput and secure smart home automation and to conserve the energy used in BLE-IoT application. The research proposes anytime anywhere communication techniques that can be used in wireless ad-hoc Network scenario like home, small city and agricultural field. The compatibility issues among the various communicating devices are solved by using Fuzzy Logic Control (FLC), a technique becoming very popular in HA system. To increase the link stability [2,7] source node selects a route-stable path by considering velocity and position of nodes for its mobility.

The [1] uses a model where the status of each IoT-device is sent to the nearby BLE nodes. This technique is enhanced to a pervasive aspect of environment.

3.1. Route stability [2]

3.1.1. Node

$$\Delta d_{i,j} = p_{i-}p_j \tag{1}$$

where: p_i, p_j position of nodei, j.

3.1.2. Velocity

$$\Delta v_{i,j} = (v_i cos\alpha - v_j cos\beta) - (v_i sin\alpha - v_j sin\beta) \tag{2}$$

where $\Delta v_{i,j}$ velocity of two IoT nodes α angle between v_i lines connected from $itoj$, β angle between v_j line connected from $itoj$.

$if\,(Direction(v_i, v_j or\ face\ to\ face))$

$\{positive\}$

$elseif\,(same\ size)$

$\{zero\}$

$else(opposite)$

$\{Negative\}$

$end\ if$

Link stability $LS_{i,j}$ node i and j calculated by membership function and fuzzy logic

Table 1
Wireless Technologies – Network Topology.

	BLE	A	A+	Zi	RF	Wi	Ni	Ir	NF
Broadcast	Yes	Yes/1	Yes/1	No	No	No	No	No	No
Mesh	Yes/2	Yes	Yes	Yes	Yes	No	No	No	No
Star	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Scanning	Yes	Yes /3	Yes	Yes	Yes	No	Yes	No	No
Point to point	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Key: BLE(Bluetooth Low energy), A(ANT),A+(ANT),Zi(Zigbee),RF(RF4CE),Wi(Wi-Fi)
Ni(Nike +), Ir(IrDA), NF(NFC)
Note:
1. Not Just broadcasting, it also needs to listen.
2. An application can be put on BLE to enable meshing.
3. All connections stop and power consumption is high.

Table 2
Wireless Technologies - Power Efficiency.

	BLE	A	Zi	Wi	Ni	Ir
A Byte consists		Tx = 32b/sec& consumes 61μA 32*8 = 256bits/sec				
power		3v*61μA = 0.183mW		116 mA*1.8v = 0.210 W	3*0.225 mA = 0.675mW	0.163mW
Power per bit	Broadcast every 500 ms, Each packet 20bytes, Payload & consumes 49μA at 3 V, 0.147mW/ 960 = 0.153 μW/bit	0.183mW/256 bits = 0.71 μW/bit	0.035706/ 192 = 185.9 μW/bit	0.210/ 40,000,00 = 0.00525 μW/ bit	0.675mW/ 272 = 2.48 μW/bit	TV remote sends 14 bit payload, 0.163 mW/14 bits = 0.111.7mW
Power consumption	49μA*3v = 0.147mW					
Bytes per/sec	20*(1sec/500 ms)*3 channels) = 120 bytes/sec		24*8 = 192 bits		34*8 = 272bits/sec	
Bites per/sec bites	120bytes/sec*8 = 960 bits/sec					14
Power per bit			185.9 μW/bit		225mAh/1000, hours = 0.225 mA	0.163mW/11.7 μW/bit
Current drawn					225mAh/ 1000 h = 0.225 mA	

Table 3
Wireless Technologies – Range.

Range	
NFC	5 cm
IrDA	10 cm
Nike+	10 m
ANT(+)	30 m
Zigbee	100 m
RF4CE	100 m
Wifi	150 m
BLE	280 m

Table 4
Wireless technology –Throughput.

Throughput	
NFC	~424kps
IrDA	~1Gbps
Nike+	~272bps
ANT(+)	~20kps
Zigbee	~100Vkps
RF4CE	~100Vkps
Wifi	~6Mbps
BLE	~305kbps

Table 5
Fuzzy conditional rules for route stability.

$\Delta d/\Delta v$	Negative	Zero	Positive
Low (L)	Medium	Very High (VH)	Average (A)
Medium (M)	Low	High	Average
High (H)	Very Low	Average	High

3.1.3. Two input variable

$\Delta d and \Delta v$ of neighbour node.

The communication Route Stability (RS) between sources 's' to destination 'd' via 'a', 'b', 'e', 'f' intermediate nodes up to of 'n' nodes.

$$RS_{s,d} = LS_{a,b} \times LS_{b,e} \times LS_{e,f} \times \cdots\cdots\cdots\cdots .. \times LS_{n,d} \quad (3)$$

Table 5 route stability includes membership functions are selected to be triangular

Fig. 2. Device Discovery and Detection of IoT enabled field devices.

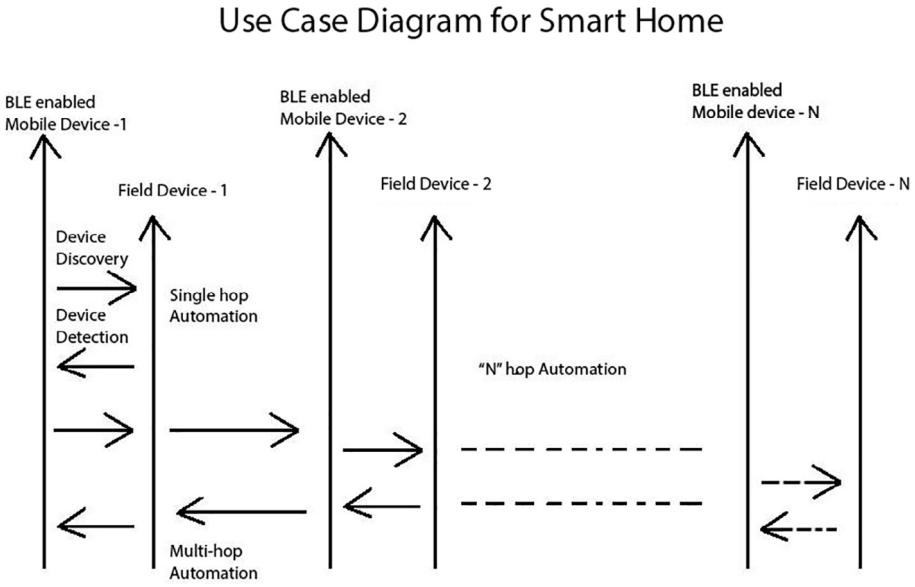

Fig. 3. Overall working model for smart home automation.

Table 6
Determined O/P value through nine fuzzy rules.

Rule	(T/W)	Battery_level	Sleeping_time
1.	Low	Low	Medium
2.	Low	Medium	Low
3.	Low	High	Low
4.	Medium	Low	Medium
5.	Medium	High	Low
6.	Medium	Medium	Medium
7.	High	Low	High
8.	high	High	High
9.	high	Medium	High

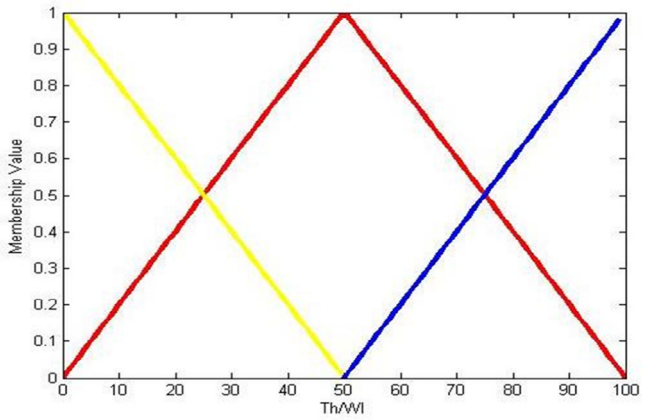

Fig. 4. Membership Value Vs. T/W.

3.2. Energy consumptions for IoT devices

The Throughput (T) → Sum of both periodic and aperiodic packets sent by the IoT-device. The Workload (W) → Total no. of packets IoT-device has to send [1].

$$P_{periodic} = \left[\frac{1}{Ts_i}\sum_{i=T_{start}}^{T_{end}} i\right] \tag{4}$$

where T_{start} and T_{end} initial and end instant of the sleep. T_{s_i} Sleeping-time of the i^{th} IoT-nodes, that corresponds with the packet radiation-time.

$$T/W = \frac{1+k}{2+k} \tag{5}$$

where k random value (represent no. of aperiodic packet to be send); 1 refers to the last periodic packet node that has to be transmit while 2 is the no. of periodic packets that fall under sleeping time → window.

$$\text{Sleeping time} = \frac{\sum_{i=1}^{n} \text{out}_i \times \quad c_i}{\sum_i^n c_i} \tag{6}$$

c_i mebership fuction, out_i rule base i

The output value in Table 4. Here single fuzzy rules such as Low, Medium, and High

$$If\left(\frac{T}{W}\right)$$

$$\{low\}$$

$$elseif(battery\ level)$$

$$\{low\}$$

$$else(sleeping\_time)$$

$$\{medium\}$$

$$end\ if$$

3.3. Algorithm for IoT device discovery and scanning using BLE

Step 1: Device Discovery (DD) initiated by source node periodically broadcasting a advertise packets to all of its connecting neighboring nodes.

Step 2: The DD packet similar for BLE protocol. Intermediate nodes

Scanning DD rebroadcast them.

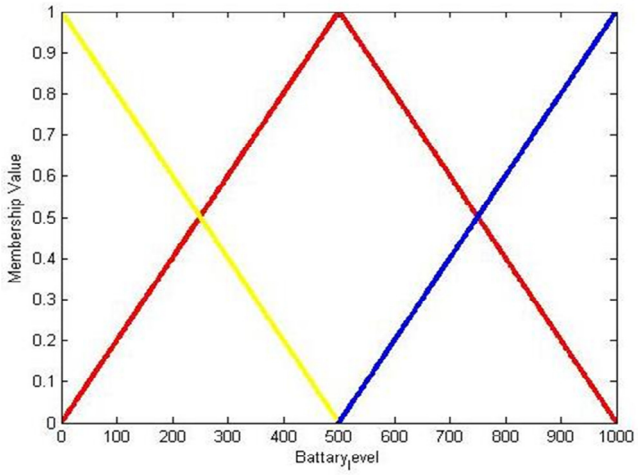

Fig. 5. Membership Vs. Battery Level.

Step 3: The destination IoT devices receive multiple DD within a time window, which replay from first arrival DD.

Step 4: In this time D' IoT device send Device Detection packet per each received DD without delay.

Step 5: Then the nodes forward Device Detection packet contains. The complete route topology from S to D is sent-back to the S node.

Step 6: The S node estimate RS receiving first Device Detection Packet and start to transmit command packet from discovery path. By receiving next DD compares.

Step 7: In their RS in this matching if S find route with higher RS it will switch transmit path to stable-path as shown in the Fig. 2. Fig. 3 pictorial representation of working model for smart home automation using IoT device discovers. Checking within RS range or not. Then if the range, it sends reply to source node via intermediate nodes.

4. Results and discussions

The experimental works is carried out in MATLAB-12b. The O/P value determined through nine fuzzy rules with respect to throughput, workload, battery level and sleeping time and is shown in Table 6. Fig. 4 represents the membership values vs T/W. The present systems consider triangular membership functions. In Fig. 4 X-axis in represents T/W and Y-axis represents membership value, where yellow color represents low, red color is medium and blue color is high. Fig. 5 represents the membership value vs battery level where X-axis represents battery level and Y-axis is membership value.

5. Conclusions

Here a fuzzy reasoning based method is obtained to enhanced link stability of nodes and life-time of IoT-devices in smart home automation. The present paper is analyzed to find the advantage and prospective of BLE has its output. The main goal of this work is to dynamically change link stability and sleeping time with increase the battery life-time of the IoT devices by its low energy consumption when compared to other algorithms.

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CRediT authorship contribution statement

Kothandaraman Dhandapani: Conceptualization, Methodology, Software, Data curation, Writing - original draft, Validation. **A. Harshavardhan:** Visualization, Investigation, Supervision, Software, Writing - review & editing. **V. Manoj Kumar:** Visualization, Investigation, Supervision, Software, Writing - review & editing. **D. Sunitha:** Visualization, Investigation, Supervision, Software, Writing - review & editing. **Seena Naik Korra:** Visualization, Investigation, Supervision, Software, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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