Fuzzy Energy Efficient Routing for Internet of Things (IoT)

Babar Shah
College of Technological Innovation
Zayed University
Abu Dhabi, UAE
babar.shah@zu.ac.ae

***Abstract*—Internet of Things (IoT) envisions the idea of universal smart connectivity of everything between physical and digital world. Every smart device in IoT consists of a power source sensors, microprocessor and transceiver module to sense, communicate and exchange data among each other. In distributed IoT networks, the energy efficiency of the smart objects is a key factor in the overall network performance. Most of the times IoT's have to deal with low power and communication disconnection due to the limited memory, processing capability, and power. Few techniques for stringent Quality of Service (QoS) routing in IoT have been proposed despite its great impact on future network. In this paper, we propose energy-efficient possibilistic routing based on fuzzy logic model for IoT to controls the transmission of the routing request packets to increase the network lifetime and decrease the packet loss. The proposed fuzzy logic controller accepts the input descriptors in routing metrics to optimize the network performance. The proposed algorithm adopts energy-efficient possibilistic routing by using fuzzy inference rules to merge energy aware metrics for choosing the optimal delivery path. In the simulations, we verify that the proposed algorithm has longer IoT network lifetime and consumes the residual energy of each smart node more consistently when compared with the existing traditional protocols.**

***Index Terms*—IoT, energy, routing, fuzzy, delay**

I. Introduction

IoT has been visualized and improved the communication and integration with smart objects known as things. The IoT network allows new systems of communication and interaction between people and smart objects and between smart objects themselves [1]. Each smart object node in IoT network communicates with other objects and thus plays a defined role in the network [2]. The smart objects or things in IoT network are equipped with sensors and radio-frequency identification (RFID) systems such that the connectivity requirements between the IoT things are achieved over wireless communication standards such as Wifi, Wimax, LTE, and cloud computing [3-5]. Thus, the things equipped with sensors in IoT network have limited computing, memory, transceiver module and power capabilities, therefore, communicate in a short-range distance [6]. In IoT, the energy constraint is a very crucial issue, as things are usually operated on limited battery power.

From building automation, automotive, smart cities and smart factories to wearables, health care and precision agriculture, the IoT touches every aspect of our lives. Thus, the main strength of the IoT network is the high impact on several aspects of everyday-life and behavior of the potential private and business users [2]. Therefore, to satisfy the demanding requirements of IoT potential users, the smart objects can sense, gather and transmit data in the IoT network in a continuous way [7]. A large number of smart objects are deployed in the IoT network and as a result a large amount of power are consumed in the whole process. To achieve this, the IoT smart objects require energy efficient communication to remain part of the smart network for a long time. Therefore, energy efficient routing plays a crucial role in the IoT to reduce power consumption and operational costs, lessen pollution and emissions and make the most of surveillance and environmental conservation [8-11].

The realization of energy efficient routing to achieve a smart communication in IoT is the research objective of this paper. Many energy efficient schemes for other networks such as, wireless sensor networks (WSN) [12-14] and ad-hoc networks [15-17] have been widely proposed in the recent past to prolong network lifetime by reducing the energy consumption of sensor nodes. However, the traditional energy efficient routing metrics defined for WSN and ad-hoc networks are not appropriate in IoT due to its dynamic network topology, insensitive packet loss, data rates, link capacity, link quality, channel diversity, interference, and various other routing requirements [1].

In this paper, we have investigated the different parameters of the smart objects to ensure an energy efficient communication in IoT network. To design an energy efficient routing protocol to provide support for IoT applications, the communication protocols must adjust their routing performance based on the IoT network parameters. However, it is not feasible to accurately and simultaneously achieve energy efficient routing, mobility of smart objects and application services in IoTs through mathematical models. To address this problem, fuzzy logic is used as an alternative model as it has potential to deal with conflicting situations and imprecision in data using heuristic human reasoning without the need of complex mathematical models [18, 19].

The dynamic nature of IoT networks due to smart objects and people mobility make the communication among smart

978-1-5386-4646-5/18/$31.00 ©2018 IEEE

objects and people more difficult. Through a fuzzy controller, an energy efficient routing is proposed to deliver the sensed data among smart objects and people in IoT network. In more detail, the proposed scheme is achieving its objective by enabling each smart object to consume energy approximately at the optimal energy consumption rate to guarantee IoT application services. Consequently, since the smart objects in IoT network may not be enough to satisfy two requirements, i.e., energy efficiency routing and mobility at once in the network for the whole period of communication. Therefore, the proposed fuzzy controller scheme adopts the input descriptors, such as mobility, Expected Transmission Based (ETX) [20], and energy for the optimal routing among smart objects in IoT. ETX is a metric that aims to provide high throughput, by measuring the packet delivery ratio of the link between neighboring nodes [1]. To adjust the optimal values of the controller, the proposed scheme utilizes standard membership functions to determine routing between smart objects in IoT network. As a result, the performance of the possibilistic energy efficient routing mechanism can be improved by only deliver the sensed data to the selected smart object in the IoT network. The objective of the proposed adaption is to not only decrease the delay and control mobility, but also to improve the successful delivery of packets through energy efficient routing in IoT. Simulation results are given to prove the effectiveness of the proposed scheme in the performance metrics.

The rest of this paper is organized as follows: Section II contains a review of related works. Section III introduces the proposed routing scheme. Section IV is the detail discussion about fuzzy logic model and Section V is the performance evaluation. Section VI summarizes the paper conclusion.

II. Related Works

IoT routing remains a hot topic in last years that has attracting the research community and thus intense works have been devoted to this field. Traditional routing protocols for Ad hoc networks and WSN can't directly applicable in IoT. Energy consumption of smart objects, mobility of smart objects, and the type of the IoT's middle-ware are three primary concerns that may affect routing in IoT [3]. Numerous energy efficient routing mechanisms have been proposed for IoT networks to efficiently communicate between things and people [1-3, 7]. This work focuses on the techniques to optimize energy efficient routing with respect to mobility and ETX. However, this section also surveys the existing routing schemes having energy, delay and other parameters for IoT networks.

Communicating sensed data from a source to a destination node is one of the most important tasks to be carried out in a large scale and dynamic IoT network. The typical reactive routing protocols such as ad hoc on-demand distance vector (AODV) [21] and dynamic source routing (DSR) [22] are designed to find just the shortest path without any consideration of the energy consumption of a node. The EEPR algorithm [1] employs both the residual energy of a node and the ETX value as the routing metrics and thus stochastically controls the number of the RREQ packets using the residual energy and ETX value of a link on the path. The EECBR algorithm [3] performed a matching between IoT events and the subscribers. EECBR routed the events through a virtual topology constructed from the bottom to the top. The variance between the remaining energy and the initial ones is very small in EECBR which allows extending the lifetime of IOT sensors. In [7], the authors proposed the framework for IoT deployment having scalability features towards more extensible. Furthermore, an optimization scheme which is constrained by the loads on wireless links and energy expenditure support the deployment of an energy efficient IoT.

In [8], the authors proposed that the green deployment schemes for IoT plays a vital role in its massive implementation. The authors investigated the problem of cost effectively arranging network objects to form a green IoT and proposed MECA leveraging the clustering principle and a Steinertree algorithm to solve the optimization problem. In [23], the authors proposed an algorithm that controls the probability of forwarding RREQ packets according to the residual energy of the node. An energy-efficient routing protocol based on AODV protocol by considering the transmission power and remaining energy capacity of the mobile nodes is proposed in [24]. Similarly, the probability based improved broadcasting algorithm [25] reduces the RREQ messages by using a broadcasting probability together with the consideration of the residual energy of nodes.

Most of the current routing protocols use hop count as their route selection metric to find the best path between source and destination smart objects of IoT. However, considering only hop count as the routing metric is not appropriate in IoT with dynamic network topology. The ETX metric [20] aims to provide high throughput, by measuring the packet delivery ratio of the link between neighboring nodes.

All the above existing schemes focused on efficient routing in different dynamic networks. However, the above methods do not consider the link quality of the route, which decreases the network lifetime by wasting the residual energy of the nodes with poor link quality. None of them tried to find solution for the reliability, scalability and quality of the required routes changes over time due to things mobility. As a result, certain logical connection can become loose which effects routing by increasing time and network overhead. One of the objectives of our proposed scheme is to route sensed data among smart objects in IoT environment with control node mobility while maintaining the smallest possible delay.

III. Proposed Routing Scheme

IoT networks has many smart objects deployed in a wide area and therefore having a more complex networking scenario than regular wireless networks. Routing of sensed data among smart objects in IoT systems is critical as end-to-end path between source and destination nodes are not guaranteed. Furthermore, the restricted wireless connectivity, amount of sensed data and smart sensor objects limited resources such as low battery energy, low power and low memory cause the increased processing requirements in large scale IoT environment more harder. The objective of the energy efficient routing for IoT problem is to ensure the IoT network lifetime at least as long as the user or application demands. Since the network lifetime comes to an end when any node collapses its energy, the best way to satisfy the IoT user or application demands for a network lifetime is to distribute energy consumption adequately among the smart nodes.

In this article, we propose an energy efficient routing with control mobility and delay for IoT systems to achieve user or application-specified network lifetime through a novel algorithm based on a fuzzy logic controller. To achieve the desired objective, we endorse a strategy where smart objects are categorized into a 3-tier model, i.e., sensing, relay and base to provide different services in IoT environment. Sensing objects lies in the tier-1 and are eligible to perform sensing and transmit the sensed data to available relay node. Thus, sensing objects have fixed and limited transmission range to transmit the data to relay objects. The tier-2 relay objects are more powerful and thus function as a local base station to collect sensed data from sensing objects in its range. The tier-3 objects are more intelligent and have high dynamic transmission range to forward data packet towards destination via internet. Tier-2 relay objects transmit data packet to other tier-2 objects or tier-3 base objects at a fixed transmission power.

To carry out IoT communications in a maximum network lifetime, the proposed scheme places the minimum number of tier-2 relay objects and tier-3 base objects in the IoT field such that each sensing object can communicate with at least one tier-2 relay object and each tier-2 object further communicate with at least one relay object in same tier and tier-3 base object relay towards the internet. The following Fig. 1 shows the 3-tiered sensing, relay and base object placement model.

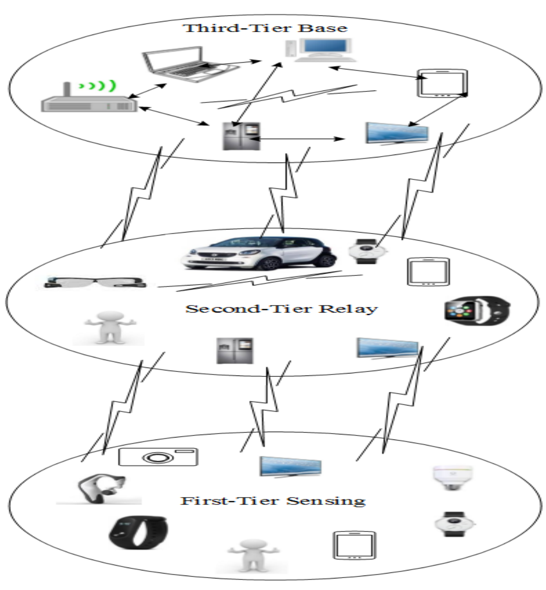

Fig. 1. System framework for IoT deployment

In the 3-tier smart object selection model, all smart objects are considered as sensing objects in the tier-1. In tier-2, a minimum number of smart objects are selected as a relay objects to ensure the connectivity of smart objects in the IoT field. Each tier-1 sensing object will be covered by at least one tier-2 relay object. Similarly, in tier-3, base objects are selected to ensure the connectivity of tier-2 relay objects and internet towards the destination object.

IV. Fuzzy Logic Model

Fuzzy logic was first introduced by Lotfi-Zadeh [26] in the mid-1960s. Since then, its applications have speedily extended due to its simplicity, clarity and suitability [6]. Therefore, instead of classical linear controllers or mathematical models, fuzzy logic controller is use in this article to perform energy efficient routing in IoT networks. Furthermore, fuzzy systems are very useful in situations involving a highly complex system whose behaviors are not well understood and in situations where an approximate, but fast, solution is warranted [11]. Since energy efficient routing, mobility, delay and ETX in IoT networks are dealing with both kinds of situations, therefore a fuzzy system can be an ideal possible solution. To deploy it in the real world, the proposed fuzzy controller algorithm must be installed on all 3-tier smart objects in IoT network.

The proposed fuzzy system consists of three parts; fuzzification, inference engine and defuzzification, as shown in Fig. 2, along with fuzzy system input descriptors. The fuzzy logic controller determines and assign a 3-tier role to smart objects based on the input descriptor to perform energy efficient communication in IoT environment.

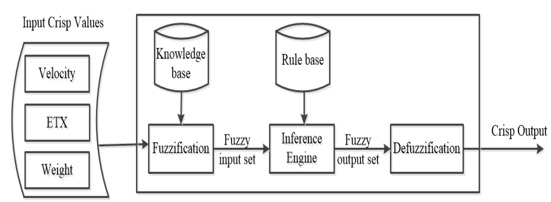

Fig. 2. Fuzzy logic system architecture

A. *Fuzzification*

In fuzzification, the input variables should be converted to linguistic values to make a crisp quantity fuzzy and determine the membership degree. In the proposed scheme, the input crisp values are mobility, ETX and energy, as shown in Fig. 2. Fuzzy logic evaluates information using fuzzy sets, each of which is represented by a linguistic variable. The fuzzy set linguistic variables, such as, very low (VL), low (L), medium (M), high (H) or very high (VH) are used in this article. Let S represent the collection of smart objects in IoT system, then a fuzzy set in S is defined by a set of ordered pairs. Moreover, the membership function $\mu(O)$ represents a degree of assets for each object O to a fuzzy set, and provides a mapping of objects to a membership value in the interval *[0 - 1]*.

The fuzzy sets *H* and *VH* contain smart objects sensing (S) in tier-1, relay (R) in tier-2 and base (B) in tier-3 having $\mu_N(S) = 1, \mu_S(R) = 1$ and $\mu_R(B) = 1$, where μ represents the degree of membership function and *N* represents the number of smart objects in the IoT network. The fuzzy set *M* contains sensing objects *S* having $\mu_N(S) > 0$, relay objects *R* having $\mu_S(R) > 0$ and base objects *B* having $\mu_R(B) > 0$. Similarly, fuzzy sets *L* and *VL* contain sensing objects *S* having $0 < \mu_N(S) < 1$, relay objects *R* having $0 < \mu_S(R) < 1$ and base objects *B* having $0 < \mu_R(B) < 1$. The outputs of this stage are fuzzy values that can be processed by the inference engine to define the fuzzy output value.

B. Fuzzy Inference Model and Rules

The fuzzy inference model performs logical reasoning and concludes a conclusion based on the empirical rules derived from the knowledge base through fuzzification. Fuzzy logic used the most trusted way of knowledge representation in inference engine, such as IF premise (antecedent), THEN conclusion (consequent), where the premise is composed of fuzzy input variables connected by logical functions and consequent is a fuzzy output variable.

The input descriptors, mobility, ETX and energy, in a proposed fuzzy control system have the linguistic values *VL*, *L*, *M*, *H* and *VH*, and the membership functions are shown in figures 3, 4 and 5 respectively. The membership functions indicate that any input descriptor value of a smart object increases or decreases, the change occurs accordingly. The proposed scheme ensures that a fuzzy controller keeps the energy consumption balance among smart objects to achieve maximum lifetime in IoT network. To show the membership function for mobility, ETX and energy, the fuzzy controller generates an output value from the set of *(0,2)* and *(0,1)*. The mobile nodes can be smart objects and/or people moving around the region or by vehicles with controlled speed $0 \leq Mobility \leq 2m/hour(h)$.

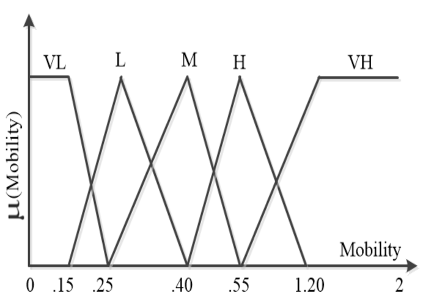

Fig. 3. Fuzzy membership function for mobility

The ETX metric is the link quality between the smart objects in IoT for the transmission required to reach to destination. In general, probe packets are used to obtain the ETX value of a link [20]. Each smart object periodically broadcasts the small-sized probe packets to its one-hop neighbor nodes. The ETX metric defined by [1] is utilized in this work. The membership function of ETX metric is shown below in Fig. 4.

To consider each smart object energy, the fuzzy controller assigns a triangular fuzzy value that specifies the range for a given level instead of a particular discrete value. Thus, the triangular fuzzy value provides an easy solution for the

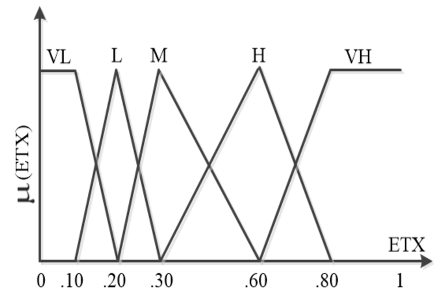

Fig. 4. Fuzzy membership function for ETX

described problem with two parameters, i.e., center point and the distance between the extreme points and the center point. To show the membership function for energy, the fuzzy controller generates an output value from the set of (0,1).

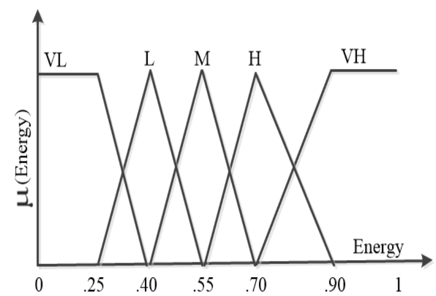

Fig. 5. Fuzzy membership function for energy

1) Rules for Tier-2 and -3 Object Selection: The last step in the fuzzy inference process is defuzzification. Fuzziness helps us to evaluate the rules, but the final output of a fuzzy system has to be a crisp number. Thus, the defuzzification process of fuzzy logic controller structure converts the fuzzy output back to the crisp or classical output to the control objective, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity [6]. The most popular and reliable defuzzification technique for actual application, i.e., Mamdani centroid technique [27] is utilized in the proposed fuzzy controller. The defuzzification phase generates two outputs tier-2 relay and tier-3 base objects. Both objects are based on the mobility, ETX and remaining energy of the smart object in IoT environment.

V. Performance Evaluation

In this section, we validate the performance of the proposed fuzzy scheme through ns-2.35 simulation tool. The IoT scenario contain total number of 150 smart objects and are completely distributed in the *500 × 500 m2* region. Initial energy of each smart object is set to *300 J*, where sensing and listening power is considered as *0.350 W* and *0.320 W* respectively. Similarly, the transmission power is assigned between *0.550 W* to *0.750 W* for tier-1, tier-2 and tier-3 layer objects. The receiving power and sensing frequency of all smart objects are assigned to *0.350 W* and *0.1 Hz* respectively. The simulation is conducted for *100* rounds. The

TABLE I
SUMMARY OF NOTATIONS USED

Rule	Mobility	ETX	Energy	Tier 2 Relay	Tier 3 Base
1	VL, L	VL,L	VL, L	VL	VL
2	M, H	VL,L	VL, L	VL	VL
3	VH	VL,L	VL, L	VL	VL
4	VL, L	VL,L	M, H, VH	L	L
5	M, H	VL,L	M, H, VH	VL	VL
6	VH	VL,L	M, H, VH	VL	VL
7	VL, L	M, H	VL, L	L	L
8	M, H	M, H	VL, L	VL	L
9	VH	M, H	VL, L	VL	VL
10	VL, L	M, H	M, H, VH	H	H
11	M, H	M, H	M, H, VH	H	M
12	VH	M, H	M, H, VH	L	VL
13	VL, L	VH	VL, L	L	L
14	M, H	VH	VL, L	L	VL
15	VH	VH	VL, L	VL	VL
16	VL, L	VH	M, H, VH	M	M
17	M, H	VH	M, H, VH	VH	VH
18	VH	VH	M, H, VH	M	H

proposed energy efficient routing scheme is compared with EEPR algorithm [1].

We validated the performance of an energy efficient IoT lifetime using the fuzzy-based algorithm. The IoT network lifetime comes to an end when all objects consumed more than *90%* of its energy and any one object collapses all its energy. The proposed fuzzy controller utilized the mobility, ETX and energy parameters among smart objects in an efficient way and thus extended lifetime of the IoT network as shown in Fig. 6. The fuzzy controller selects tier-2 relay and tier-3 base objects on defined inference rules to keep level of energy balance among all things in the IoT network. The total energy consumption among smart objects in total simulation time is illustrated in Fig. 6, where a smart object is transmitting packets to its neighbor relay node toward the base. The IoT network lifetime based on EEPR algorithm comes to an end at *4300s* where the lifetime is extended to *5500s* by proposed fuzzy scheme.

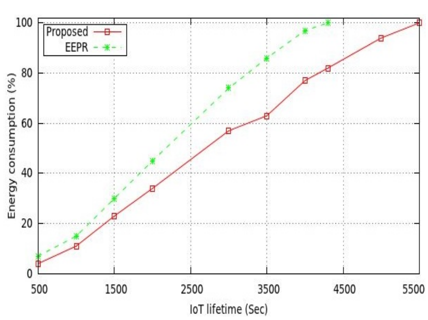

Fig. 6. IoT lifetime *VS* Energy consumption

The routing delay in this article is defined as, how long it takes for a bit of data to travel across the IoT network from source to destination object. Routing delay is directly affected by changes occurred in network load and objects mobility. When the tier-1, -2 and -3 smart objects mobility is between $1 \leq Mobility\ Speed \leq 2m/h$, the routing is hard and as a result the delay is also high. The delay in EEPR algorithm is good at the beginning of the communication where less number of objects are involved in sensing and transmitting of sensed data as shown in figure 7. As the network active for log time and more smart objects start sensing and sharing the delay ratio also increased in EEPR and reached to *2.50s*. The delay ratio in the proposed scheme is controlled from the begging to end of the network and recorded below *1.7s* when the network is fully loaded. The proposed fuzzy controller showed an acceptable value for delay for loaded and mobile IoT network shown in Fig. 7.

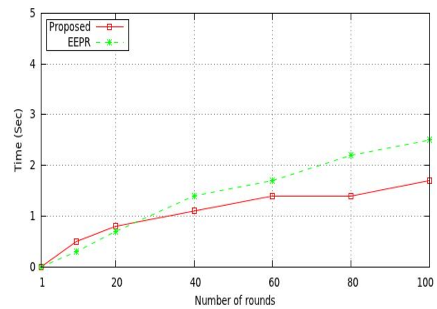

Fig. 7. Routing delay at $0 \leq Mobility\ Speed \leq 2m/h$

Performance comparison of successful data packets in an energy efficient routing between the proposed fuzzy scheme and EEPR is discussed in this section. To evaluate the performance of packet in Fig. 8, the simulation is performed on the average ratio of successful end-to-end packets delivery between source and destination objects. The proposed protocol selects the tier-2 relay object and tier-3 base object through the fuzzy controller to achieve the end-to-end successful transmission in the IoT network. The simulation is run for *100* times considering different settings of packet and plotted the average results in Figure 8. Furthermore, it is discerned from Figure 8, that the proposed scheme improves the successful packet delivery ratio to more than *94%* within acceptable deadline for traffic of different priority levels as compared to EEPR scheme achieved less than *90%* successful packet delivery.

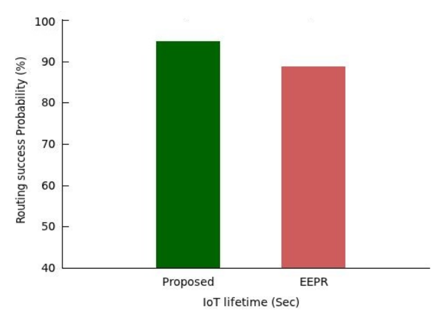

Fig. 8. Packet routing at $0 \leq Mobility\ Speed \leq 2m/h$

VI. Conclusion

In this paper, a new energy efficient routing algorithm with control mobility and acceptable delay is proposed for IoT network. The proposed energy-efficient possibilistic routing algorithm based on fuzzy logic model for IoT controls the transmission of the routing packets to increase the network lifetime and decrease the packet loss. The energy efficient routing is achieved through fuzzy controller by using mobility, ETX and energy as input descriptors. It is proved that fuzzy logic is an accurate mechanism applied to any conflicting parameters in IoT applications for effective and efficient routing. Furthermore, the design of the fuzzy-logic system is simple and easy, which allows users/applications to define different variables, sets and rules, depending on environment and the smart object features. Simulation results show that the proposed fuzzy algorithm has longer network lifetime, less transmission delay and high packet delivery ratio when compared with other protocols for IoT.

Acknowledgment

This work was supported by the Cluster Research Fund (Activity Code R18027) through the Zayed University, Abu Dhabi, UAE.

References

[1] S. Park, S. Cho and J. Lee, Energy-Efficient Probabilistic Routing Algorithm for Internet of Things, Journal of Applied Mathematics Vol. 2014, Article ID 213106, 2014.

[2] L. Atzori, A. Iera and G. Morabito, The internet of things: a survey, Computer Networks, vol. 54, no. 15, pp. 2787-2805, 2010.

[3] S. A. Chelloug, Energy-Efficient Content-Based Routing in Internet of Things, Journal of Computer and Communications, vol. 03, no. 12, pp. 9-20, 2015.

[4] A. M. C. Souza and J. R. A. Amazonas, A New Internet of Things Architecture with Cross-Layer Communication, Proceedings of the 7^{th} International Conference on Emerging Networks and Systems Intelligence Emerging, pp. 1-6, Nice, 19-24 July 2015.

[5] M. P. Michael and M. Darianian, Architectural Solutions for Mobile RFID Services on Internet of Things, Proceedings of the IEEE Congress on Services - Part I, USA, 6-11 July 2008.

[6] B. Shah, F. Iqbal, A. Abbas and K.-I. Kim, Fuzzy Logic-Based Guaranteed Lifetime Protocol for Real-Time Wireless Sensor Networks, Sensors, vol. 15, pp. 20373-20391, 2015.

[7] S. Rani, R. Talwar, J. Malhotra, S. H. Ahmed, M. Sarkar and H. Song, A Novel Scheme for an Energy Efficient Internet of Things Based on Wireless Sensor Networks, Sensors, vol. 15, pp. 28603-28626; 2015.

[8] J. Huang, Y. Meng, X. Gong, Y. Liu and Q. Duan, A novel deployment scheme for green Internet of Things, IEEE IoT Journal. Vol.1 , pp. 196-205. 2014.

[9] V. Jelicic, M. Magno, D. Brunelli, G. Paci and L. Benini, Context-adaptive multimodal wireless sensor network for energy-efficient gas monitoring, IEEE Sensors journal, vol. 13, pp. 328-338. 2015.

[10] L. Xiang, J. Luo, C. Deng, V. A. Vasilakos and W. Lin, DECA: Recovering fields of physical quantities from incomplete sensory data, Proceedings of the 9^{th} Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON), pp. 182190, Seoul, Korea, 18-21 June 2012.

[11] B. Shah, A. M. Khattak and K. -I. Kim, A Fuzzy Logic Scheme for Real-time Routing in Wireless Sensor Networks, Proceedings in 6^{th} IEEE International Conference on Computing Communication and Networking Technologies, Texcas, USA, July 13-15, 2015.

[12] H. M. Ammari and S. K. Das, Centralized and clustered k-coverage protocols for wireless sensor networks, IEEE Transactions on Computers, vol. 61, pp. 118-133, 2012.

[13] T. Yardibi and E. Karasan, A distributed activity scheduling algorithm for wireless sensor network with partial coverage, Wireless Networks, vol. 16, pp. 213-225, 2010.

[14] B. Shah and K. -I. Kim, A new real-time and guaranteed lifetime protocol in wireless sensor networks, International Journal of Distributed Sensor Networks. Vol. 2014, pp. 11-22, 2014.

[15] F. Li, J. Luo, W. Wang and Y. He, Autonomous Deployment for Load Balancing-Surface Coverage in Sensor Networks Wireless Communications, IEEE Transaction of Wireless Communication, vol. 14, pp. 279-293, 2015.

[16] P. Wei, S. Chu, X. Wang and Y. Zhou, Deployment of a reinforcement backbone network with constraints of connection and resources, Proceedings of the IEEE 30^{th} International Conference on Distributed Computing System (ICDCS), pp. 1019, Genova, Italy, 21-25 June 2010.

[17] F. Li, J. Luo, S. Q. Xin, W. P. Wang and Y. He, Laacad: Load balancing k-area coverage through autonomous deployment in wireless sensor networks, Proceedings of the IEEE 32nd International Conference on Distributed Computing System (ICDCS), pp. 566575, Macau, China, 18-21 June, 2012.

[18] D. F. Macedo, A. L. Santos, J. M. Nogueira, G. Pujolle, Fuzzy-based load self-configuration in mobile P2P services, Computer Networks, Vol. 55, 1834-1848, 2011.

[19] A. M. Ortiz, F. Royo, T. Olivares, J. C. Castillo, L. O. Barbosa and P. J. Marron, Fuzzy-logic based routing for dense wireless sensor networks, Telecommunication Systems, vol. 52, pp. 2687-2697, 2013.

[20] D. S. J. De Couto, D. Aguayo, J. Bicket and R. Morris, A high-throughput path metric for multi-hop wireless routing, Wireless Networks, vol. 11, pp. 419-434, 2005.

[21] C. E. Perkins and E. M. Royer, Ad-hoc on-demand distance vector routing, Proceedings of the 2^{nd} IEEE Workshop on Mobile Computing Systems and Applications (WMCSA '99), pp. 90-100, February 1999.

[22] B. D. Johnson, Dynamic source routing in ad hoc wireless networks, Mobile Computing, vol. 353, pp. 153-181, 1996.

[23] X. Wang, L. Li, and C. Ran, An energy-aware probability routing in MANETs, Proceedings of the IEEE Workshop on IP Operations and Management (IPOM '04), pp. 146-151, October 2004.

[24] A. P. Patil, Design of an energy efficient routing protocol for MANETs based on AODV, International Journal of Computer Science Issues, vol. 8, pp. 215-220, 2011.

[25] P. Nand and S. C. Sharma, Probability based improved broadcasting for AODV routing protocol, Proceedings of the International Conference on Computational Intelligence and Communication Systems (CICN '11), pp. 621-625, October 2011.

[26] L. A. Zadeh, Fuzzy sets, Information and Control, vol. 8, pp. 338-353, 1965, .

[27] E. H. Mamdani and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller," International Journal of Man-Machine Studies, Vol. 7, pp. 1-13, 1975.