Improving IoT Applications Using a Proposed Routing Protocol

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ABSTRACT

The main objective of this work is to propose a new routing protocol for wireless sensor network employed to serve IoT systems. The routing protocol has to adapt with different requirements in order to enhance the performance of IoT applications. The link quality, node depth and energy are used as metrics to make routing decisions. Comparison with other protocols is essential to show the improvements achieved by this work, thus protocols designed to serve the same purpose such as AODV, REL and LABILE are chosen to compare the proposed routing protocol with. To add integrative and holistic, some of important features are added and tested such as actuating and mobility. These features are greatly required by some of IoT applications and improving the routing protocol to support them makes it more suitable for IoT systems.

The proposed routing protocol is simulated using Castalia-3.2 and all the cases are examined to show the enhancement that achieved by each case. The proposed routing protocol shows better performance than other protocols do regarding Packet Delivery Ratio (PDR) and latency. It preserves network reliability since it does not generate routing or data packets needlessly. Routing protocol with added features (actuating and mobility) shows good performance. But that performance is affected by increasing the speed of mobile nodes.

Keywords: internet of things, routing protocol, wireless sensor network, castalia-3.2.

تحسين تطبيقات انترنيت الأشياء باستخدام بروتوكول توجيه مقترح

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الخلاصة

الهدف الرئيسي من هذا العمل هو اقتراح بروتوكول توجيه جديد لشبكة الاستشعار اللاسلكية المستخدمة لخدمة أنظمة إنترنيت الأشياء . بروتوكول التوجيه المقترح عليه التكيف مع متطلبات مختلفة من أجل تعزيز أداء التطبيقات الخاصة بإنترنيت الأشياء. تم إستخدام نوعية الارتباط ، وعمق العقدة و الطاقة كمقاييس لاتخاذ قرارات التوجيه. المقارنة مع البروتوكولات الاخرى أمر ضروري لإظهار التحسينات التي تم تحقيقها من خلال هذا العمل، وبالتالي تم اختيار بروتوكولات مصممة لخدمة نفس الغرض مثل AODV ، REL و LABILE لمقارنة البروتوكول المقترح في هذا العمل معها. لإضافة التكاملية و الشمولية، تم إضافة بعض الميزات الهامة واختبارها مثل دعم تطبيقات التفعيل ودعم خاصية الحركة للعقد. هذه الميزات مطلوبة بشكل كبير من قبل بعض تطبيقات إنترنيت الأشياء وتحسين بروتوكول التوجيه لدعمها يجعلها أكثر ملاءمة لأنظمة إنترنيت الأشياء.
تم اختباربروتوكول التوجيه المقترح باستخدام نظام المحاكاة Castalia-3.2 وتم فحص جميع الحالات لإظهار التحسينات التي تم تحقيقها في كل حالة. حقق بروتوكول التوجيه المقترح أداء أفضل من البروتوكولات الأخرى فيما يخص نسبة تسليم البيانات والتأخير. فإنه يحافظ على موثوقية الشبكة لأنه لا يولد حزم البيانات بصورة عشوائية أو بدون حاجة. بروتوكول التوجيه مع الميزات المضافة (دعم المشغلات والتنقل) يظهر أداء جيدا. ولكن يتأثر هذا الأداء من خلال زيادة سرعة العقد المتنقلة.

الكلمات الرئيسية: إنترنيت الأشياء, بروتوكول توجيه، شبكة الإستشعار اللاسلكية.

1. INTRODUCTION

The Internet of Things (IoT) applications are the new area of IT fields, these applications aim to collect the data from different sensing resources and transmit them to the internet, and then take a decision according to the different types of data captured and reply with an action after analyzing the data this action may deal with one or more devices according to the way the IoT server handles and analyzes the data, **Mazhelis, et al., 2013** and **Gubbi, 2013**. The data may be related to environment, business, society or health **Su, et al., 2013**, **Yang, and Pan, 2013**. Great diversity of IoT applications makes it necessary to build a routing protocol that can handle the differences among these applications and satisfy all the requirements needed to achieve the expected performance. The behavior of these applications must be taken into account during the design process, since IoT application collecting data mechanism contributes in defining the topology, and then imposes the Mechanisms used by the routing protocol to perform its task effectively.

It is essential to select routing metrics that routing protocol can use in the decision process. Link quality is the most important metric to be taken into account. The link quality can be calculated as signal to noise ratio (SNR), or signal to interference ratio (SINR) as an indicator of link status, **Baumann, et al., 2007** and **Rondinone, et al., 2008**. The energy metric will play an important role in routing decision process, **Su, et al., 2013, Patel, et al., 2013** and **Sridevi, et al., 2013**. The energy metric can be calculated as remaining energy or the ratio of the remaining energy to the total energy defined for each node, and sometimes the designer needs to select the node with the highest energy level and this can be done by avoiding the path having a node with minimum energy level, **Baumann, et al.,** and **2007**, **Chipara, 2010.** It may be required to use hop count metric to control the packet path and avoid using of path with too many hops which may lead to consume more energy and increase the latency **Machado, et al., 2013**, **Al-Fagih, 2013,** and **Farooq,** and **Jung, 2013**.

Change in mobility state of the nodes confers a kind of complexity to the design. The required Protocol must possess the ability to deal with all nodes regardless of their state. The nodes dealing with this type of routing protocol have to support the dynamic routing. So these nodes can deal with all other nodes without limitations. And that must be done by supporting different mechanisms to deal with messages from other nodes and not by imposing mechanism that are not used by other nodes. This approach facilitates the communication between the heterogeneous nodes and increases the network performance. The IoT routing protocol should serve the actuating data as well as the sensed data. Some IoT applications greatly rely on the data sent by the IoT server to the smart objects. The routing protocol must be fluent in dealing with this type of data and act with the same efficiency that it deals with data obtained from sensors. The powerful simulation tool that may be used to evaluate the mentioned cases is Castalia-3.2, which is designed for simulating wireless sensor network (WSN), Body Area Network (BAN) and generally networks of low-power embedded devices. It is based on the OMNeT++ platform which is an object-oriented modular discrete event simulator, **Boulis, 2009**, and **Varga, 2003**.

2. ROUTING PROTOCOL BASED ON ENERGY AND LINK QUALITY INDICATOR WITH LEVEL CONSTRAINT

End-to-end link quality will be calculated according to number of unreliable links along the path to the destination (SINK node). This mechanism will assign a quality indicator to reflect how many bad links there are in the path. The proposed routing protocol will start when the sink node broadcasts a control packet in the initialization phase including the source address and the remaining energy. This packet will be useful to acquire link quality value of related link and to define the levels of nodes receiving this packet. Each node on receiving this control packet will wait for a period of time and rebroadcast the control packet to its neighbors after updating the packet fields.

After defining the level, a sink node will start a link quality calculation phase by broadcasting another packet to the neighboring nodes. This packet will have source field, normalized link quality of previous link field and link quality indicator field. Each node will set the link quality bad indicator according to their parents (nodes with level lower than the level of the current node); the node will decide that it has bad link quality if its next level parents have link quality values under LQ_{th}. So that the node will not broadcast a link quality packet until it receive the link quality packets from its parents, then the node will broadcast its link quality packet to inform its neighbors about its relationship with its parents. The normalized link quality value and bad link quality indicator are calculated according to Eq. (1) and Eq. (2), respectively:

$$Normalized\ link\ quality = \frac{(current\ lq * normalized\ previous\ lq)}{(current\ lq + normalized\ previous\ lq)/2} \quad (1)$$

$$Bad\ indicator\ = current\ bad\ link\ indicator\ +\ previous\ bad\ link\ indicator \quad (2)$$

After completing this process, the node will transmit or forward the data packet according to routing decision process described in algorithm 1:

Algorithm 1. Routing Decision Process.

1- Limit the search process to the parents (current level > next hop level).
2- Set the bad link indicator for the related link.
  - If link quality <LQ_{TH}
    - Then set currentbadlink indicator = 1
  - Otherwise
    - Set currentbadlink indicator = 0
3- Search for the route with minimum *Bad indicator.*
  - This condition assumes the availability of sufficient remaining energy of candidate node.
4- If there are more than one route with the same Bad indicator value.
  - Search for the route that satisfy the optimization problem:

Maximize

$$(Normalized\ link\ quality \times 0.5) + (remaining\ energy \times 0.5)$$

$$Subject\ to \quad (3)$$

$$Current\ level > next\ hop\ level$$
$$(current\ blqi\ +\ previous\ blqi)_S =\ (current\ blqi\ +\ previous\ blqi)_o$$

Where

blqi: bad link quality indicator.
S: selected route.
O: other routes.

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3. ACKNOWLEDGEMENT AND ERROR CHECK

There are two approaches to handle the error check in order to ensure that the packets are delivered correctly to the final destination. The first approach is done by the network layer when the node receiving the packet responds by sending acknowledgement to the sender node. This approach will increase the flow of packets in the network and may cause high latency since the packets have to wait in the network layer TXbuffer until the acknowledgement is received. The packet forwarding and acknowledgement mechanism can be described in the algorithm 2:

Algorithm 2. Packet forwarding and acknowledgement

1- Find the route to forward the packet.
2- Store a copy of the packet in network layer TXbuffer.
3- Wait for acknowledgement.
   - If acknowledgement is received within specific time.
     - ✓ Remove the copy of specified packet.
   - Else
     - ✓ Send a copy of packet again and wait for acknowledgement.
4- Repeat sending packet until receiving acknowledgement or exhausting all the tries of transmitting as configured in the protocol.

The second approach is done by the MAC layer which is the last layer dealing with the packet; therefore this layer will have error check and retransmission mechanism. In this work, the proposed routing protocol relies on MAC protocol to handle the error check and acknowledgement which is supported by the simulator. The proposed routing protocol is designed to support real time connection, thus the network layer error check mechanism will double the packets that entering the network and may exploit the network resources and badly affect the performance.

4. ACTUATING PACKETS ROUTING

The proposed routing protocol handles the actuating packets by exploiting the same algorithm used in the approach in section 2. After implementing the routing tables, the nodes start transmitting their data packets and forwarding them to the SINK node. Each node, on receiving data packets, will implement another table to keep information about the source of data packets. Each node will store the information related to data packets which include the original sender and last forwarder. The SINK node and other forwarders will use this table to extract the next hop toward the destination (smart object of interest). The node will search its table for information related to the original sender which represent the destination of the control packet, the last forwarder will be the next hop of control packet. Forwarding of actuating packet process is shown in **Fig. 1.**

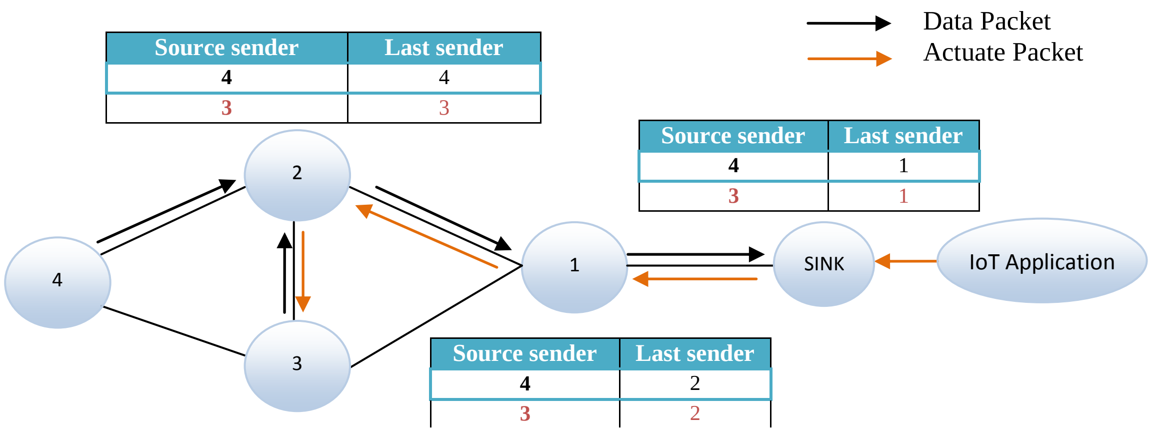


Figure 1. Forwarding actuating packet.

5. HANDLING MOBILITY

The proposed routing protocol will support both types of nodes, stationary and mobile nodes in order to give nodes the capability to support dynamic routing. The static node will forward their packets according to the proposed routing protocol in section 2. While the mobile nodes will follow a different procedure to send their packets and deliver them to the stationary node in order to ensure delivering them to the destination. Due to mobility, the mobile node may have different neighbors each time it tries to send data packets; therefore the mobile node will not take part in initialization phase to exchange control packets and will not send or forward link quality packets.

Each mobile node that has a data packet to transmit will broadcast RREQ packet to ask for available route to transmit its packet. The mobile node will store the data packet in the TXbuffer until receiving permission from its neighbors. The mobile node also stores its current geographical location to be used in routing decision process. The stationary node, on receiving RREQ packet, replies by sending RREP packet which includes the geographical location and the remaining energy of stationary node. Then the mobile nodes, on receiving RREP packet, will calculate whether the stationary node related to the RREP packet is suitable to be the next hop the destination or not. The routing decision process will be based on geographical locations, link quality and energy. The data transmission mechanism can be described in the algorithm 3:

Algorithm 3. Transmitting of mobile node data packet

1- Arriving of data packet from application layer.
2- Store a copy of packets in TXbuffer and record the geographical information.
3- Broadcast RREQ packet.
4- Upon receiving RREP from neighboring node, the mobile node selects the available route according to the following:
   - Store the new geographical information.
   - Calculate the distance to the specified stationary node using the old stored geographical information using Eq. (4):

$$old\ distance = \sqrt{(OGM_x - GS_x)^2 + \left(OGM_y - GS_y\right)^2} \tag{4}$$

$Where$:
OGM :The old geographical location of mobile node.
GS :The geographical location of stationary node.

- Calculate the distance to the specified static node using the current stored geographical information using Eq. 5:

$$current\ distance = \sqrt{(CGM_x - GS_x)^2 + \left(CGM_y - GS_y\right)^2} \quad (5)$$

$Where$:
CGM :The current geographical location of mobile node.
- Acquire the energy and link quality information from RREP packet.
- The next hop candidate should satisfy the following conditions:
  - ✓ Sufficient remaining energy:
    $$\text{Remaining Energy}/\text{Initial Energy} > 10\%$$
  - ✓ Acceptable link quality value:
    $$Link\ quality > LQ_{TH}$$
  - ✓ Acceptable change in distance to ensure acceptable decreasing in Link quality value:
    $$current\ distance < old\ distance$$
    OR
    $$(old\ distance - current\ distance) < (0.25 \times old\ distance)$$

5- Send all the data packets in the TXbuffer to the selected static node.
6- When no nodes that sent RREP packet can satisfy the condition then Store the packet in TXbuffer and Wait for the next data packet

The stationary nodes have no available routes to the mobile nodes in their routing table, since the mobile nodes do not transmit any control or link quality packets. But the stationary nodes support both stationary and mobile nodes. This mechanism allows the dynamic routing and satisfies the requirement of IoT data Acquisition layer. The mobile nodes route request and data packets transmitting is shown in **Fig. 2**:

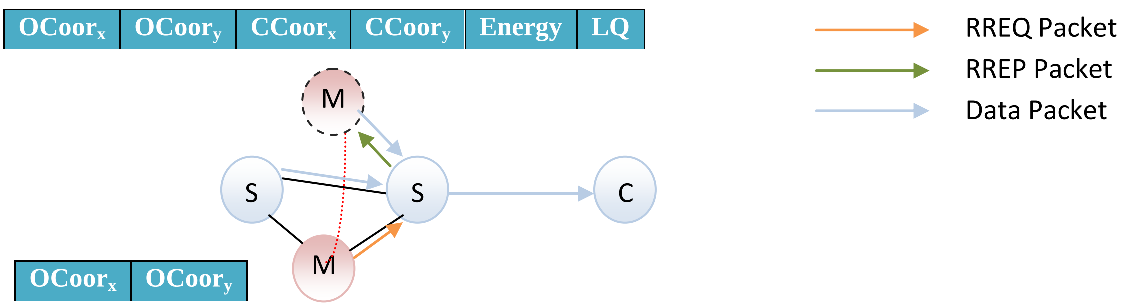


Figure 2. Route request and data transmitting of mobile nodes.

6. RESULTS AND DISCUSSION

6.1 Comparison with Other Protocols

The proposed routing protocol is tested as compared to other protocols in order to show the enhancement provided by this protocol which is represented by achieving the best results in different performance criteria. The routing protocols chosen to compare the proposed routing protocol with are:

- **AODV** Flat Routing Protocol v1 (Ad hoc on demand distance vector **(RFC 3561)).**
- **LABILE** Flat Routing Protocol v1 (Labile: Link quality-based lexical routing metric for reactive routing).
- **REL** Flat Routing Protocol (A Routing Protocol Based on Energy and Link Quality for Internet of Things Applications).

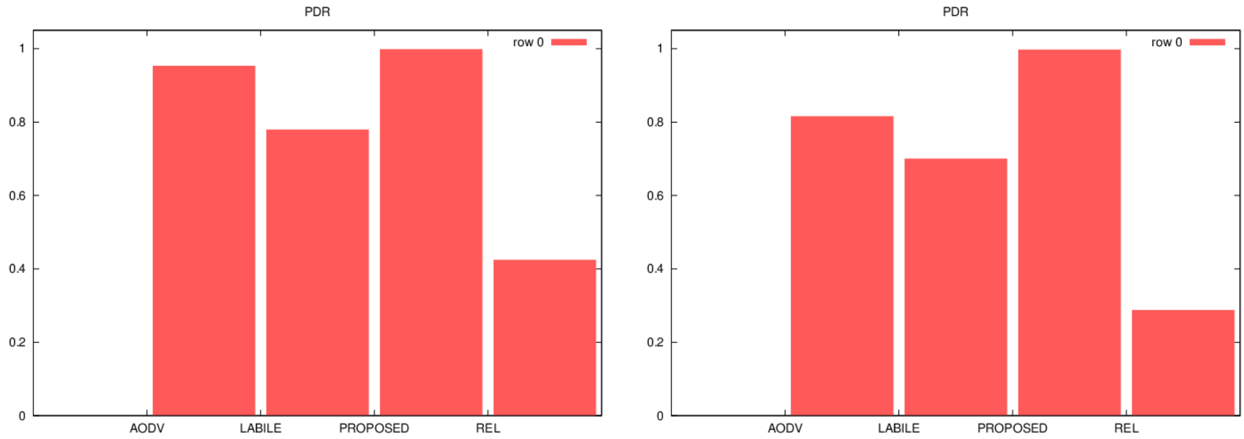
All protocols are simulated using the default configurations equipped with other protocols (AODV, LABILE, REL). These configurations are listed in Table 1 shown below:

Table 1. Configuration used to compare protocols.

Number of nodes	50, 70
Simulation time	100 s
Field(x,y)	(30,30),(36,36)
Deployment	uniform
Initial energy	100
MAC protocol name	Tunable MAC
Application name	Throughput Test
Constant Data Payload	100
Application Packet rate	1
Startup Delay	0

The simulation shows the best results recorded by the proposed routing protocol as compared to other protocols as shown in **Fig. 3**. Since this protocol achieves high packet delivery ratio when tested using different area and number of nodes (PDR exceeds 99%). AODV records the second best result for both cases. For the first case (a), AODV achieves (95.3%). But it cannot keep this level when enlarging the field area and increasing the number of nodes as shown in **Fig. 3** (b). AODV achieves PDR value of 81.548% in the second case. Both REL and LABILE protocol show Bad PDR values, especially when increasing number of nodes and enlarging the area field.

The degradation in PDR value of these protocols is due to lose of large number of packets because of buffer overflow in communication routing layer. The REL and LABILE use mechanisms of routing that keep the packets for long time in the routing layer which may cause collecting large number of packets in this layer, thus losing new packets that are arriving but cannot find valid locations in routing layer buffer to wait for processing. The proposed protocol and AODV have no such problem because the packets do not have to wait in the network layer; the packets are processed and delivered to the MAC layer upon arrival from application or MAC layer. Losing of packets increases with increasing number of nodes and enlarging the field because of larger number of packets will enter the network and need to be processed. This problem may be caused also because of usage of number of hops as a constraint in these protocols. As depending on large number of hops may allow packets to traverse many hops before been delivered to the SINK node, thus increasing the traffic in the network.

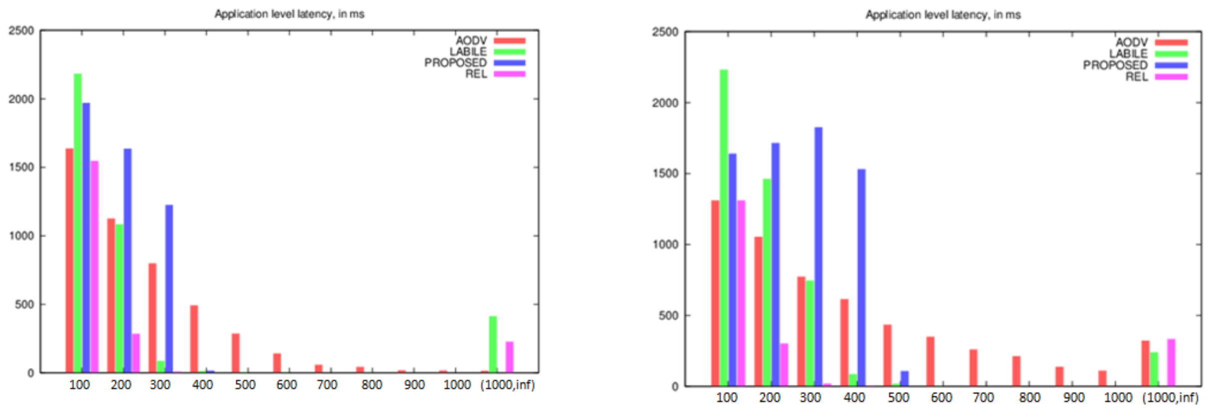


(a) (b)

Figure 3. Packet delivery ratio (a) 50 nodes, (b) 70 nodes.

The application latency results in **Fig. 4** shows best results for proposed routing protocol as taking into account the number of packets delivered correctly. The LABILE protocol seems to provide good results for large amount of packets (latency of less than 100 ms), but some packets processed by this protocol are delayed to more than 1 second. The same behaviour can be seen related to REL protocol, notice that the packets delivered by this protocol is much less the packets delivered by LABILE protocol. AODV shows reliable behaviour, but the latency recorded by this protocol still does not achieve the requirements, especially for such area fields and number of nodes. **Fig. 4** shows that the proposed protocol can deliver the packets in less than 300 ms for the first case and in less than 500 ms in the second case.

The increasing of number of nodes and enlarging the field will increase the node levels, thus increasing the hops required to reach the destination. The contention to get the carrier will be increased and the nodes that fail to win the carrier have to wait for (0.128 s) before next try to get the carrier in addition to other mechanisms that causes the delay such as back off time (16 ms). The contention problem increased with increasing the packet size, since the transmitting node will keep using the link to transmit a packet while other nodes try to get the link. The contention problem and latency increase with increasing the overhead caused by mechanism of specific protocol. AODV, REL and LABILE use RREQ and RREP mechanism during the initialization phase in order to discover the route to the destination.



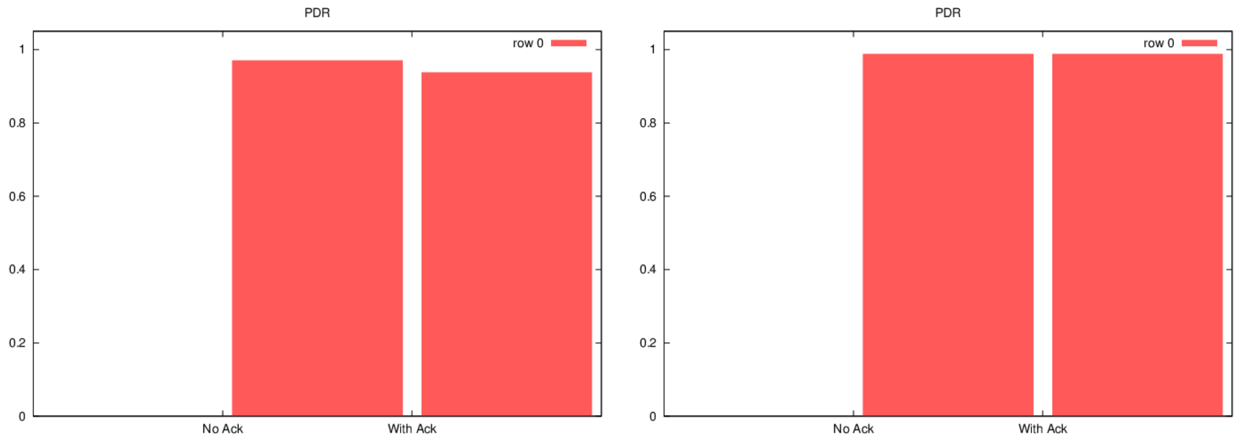
(a) (b)

Figure 4. Application latency (a) 50 nodes (b) 70 nodes.

Actually, each node has to broadcast different types of packet in order to define the route to SINK node. In spite of that, most of these types will not have high payload, but it may cause high traffic in the network that may cause collision and losing packets, as well as increasing the contention and increasing the latency.

6.2 Acknowledgement and Error Check

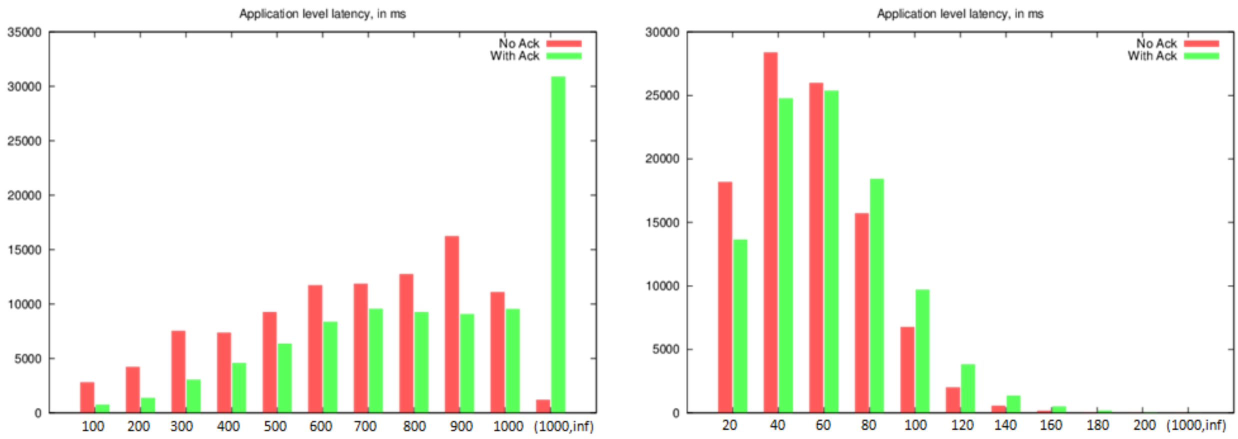
The proposed routing protocol is simulated with and without the acknowledgement mechanism to show the impact of carrying out error check in the network layer. The protocol is tested using two different applications; the first application is throughput test which is using high payload (100 Bytes) and the second application is value reporting application which uses lower payload (12 Bytes). Both experiments are done using 100 nodes and the simulations are run for 1000 seconds. The results in **Fig. 5 (a)** show better packet delivery ratio when relying on MAC protocol for error check. Notice that the acknowledgement mechanism will cause MAC buffer lack problem; therefore it's necessary to use higher MAC buffer in order to reduce the impact of this problem and achieve higher packet delivery ratio (MAC Buffer = 64 or higher). The **Fig. 5 (b)** shows that PDR is not affected when reducing the payload which represents the most normal configurations for wireless sensor network. Notice that reducing data rate of throughput test to 0.5 (sending 1 packet each 2 seconds) will record PDR of 97.1%.



(a) (b)

Figure 5. PDR for data rate 1 with different applications (a)throughput test (b)value reporting.

The error check mechanism will greatly affect the latency for both types of applications, because this mechanism will increase the number of packets flowing in the network which increases the contention and causes the packets to be delayed until the acknowledgements are received. The application level latency for both applications with/or without acknowledgement is shown in **Fig. 6. Fig. 7** shows the increasing of packets when using acknowledgement mechanism, and also shows the overflow caused by this mechanism in spite of enlarging the MAC Buffer.



(a) (b)

Figure 6. Latency for different applications (a) throughput test (b) value reporting.

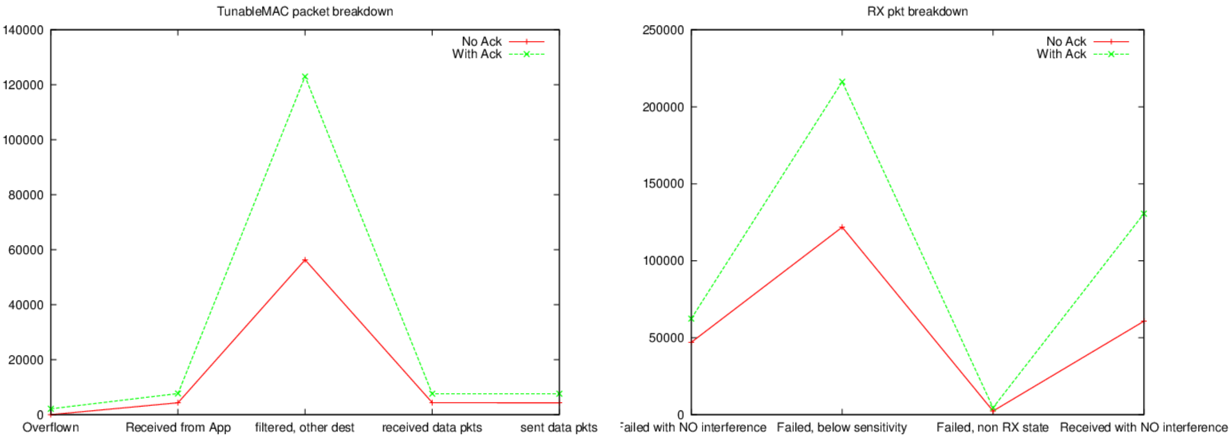


Figure 7. packets generated due to using proposed protocol

6.3 Sensing and Actuating Routing

The proposed routing protocol supporting the actuating capabilities is simulated with 100 nodes and 1000 second for simulation time. The results show acceptable PDR and latency for actuating various nodes which represents different levels in the network. PDR and latency results of actuating nodes are listed in **Table 2.**

Table 2. PDR and Latency of different level nodes

	Node 39	**Node 2**	**Node 91**
	Level 3	Level 5	Level 8
PDR	94.949%	95.959%	95.959%
Latency	0.33018s – 0.908s	0.84199s – 0.925s	0.81303s – 1.084s

6.4 Dynamic Routing Simulation

The routing decision process of mobile nodes is simulated using four mobile nodes which are moving linearly in the field. The configuration of simulation is listed in **Table 3** below:

Table 3. Mobility simulation configuration.

Number of nodes	54			
Simulation time	1000 s			
Field(x,y)	(71,71)			
Deployment	[0..49]->uniform			
Initial energy	100			
[0..49].Mobility manager name	No Mobility Manager (Stationary nodes)			
[50..53].Mobility manager name	Line Mobility Manager (Mobile nodes)			
Mobility manager speed	5,10,15			
	Node 50	**Node 51**	**Node 52**	**Node 53**
Initial location	(0,0)	(71,0)	(35,0)	(0,35)
Destination	(71,71)	(0,71)	(35,71)	(71,35)
Application name	Throughput Test			
MAC protocol name	Tunable MAC			
MAC Buffer size	32			
Application packet rate	1			

The results of simulating the proposed routing protocol for mobile nodes show highly acceptable packet delivery ratio for all mobile nodes with different suggested speed. The PDR decreases slightly when increasing the speed. Actually, it is not possible to completely relate the PDR to the speed of mobile nodes. PDR may depend on many parameters such as end-to-end link quality when mobile node successes in delivering the packet to the stationary node but the stationary node fails in delivering the packet successfully. PDR values for different speeds are listed in **Table 4.**

Table 4. PDR of mobile nodes and different speeds.

	Node 50	**Node 51**	**Node 52**	**Node 53**
Speed 5	95.095%	95.595%	93.393%	93.193%
Speed 10	93.693%	92.892%	94.594%	93.793%
Speed 15	93.993%	93.593%	91.991%	91.691%

All cases record acceptable application level latency, since all packets from mobile nodes arrives to their destination with latency ranges between 0.1s - 0.6s. The latency of individual packet may rely on the selection process, since the stationary node must satisfy routing conditions imposed by mobile nodes before the packets can be transmitted. Therefore packets considered to be delivered quickly may be delayed until finding the required node. The latency results of mobile nodes are shown in **Fig. 8.**

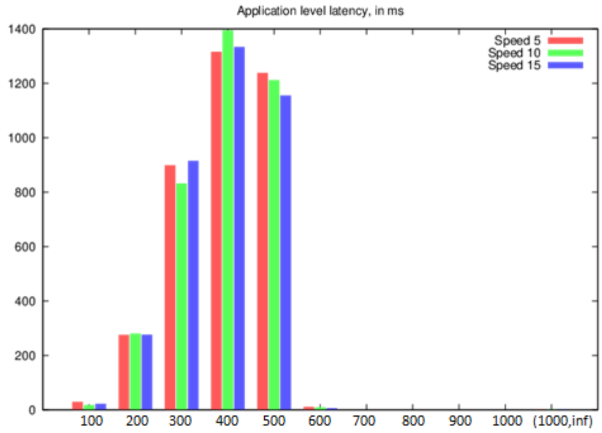


Figure 8. Latency of mobile nodes packets with different speed.

7. CONCLUSIONS

Sensing and actuating IoT applications require that routing protocol must deal with both types of data and forward them correctly to their last destination; each type requires different algorithm. End-to-end link quality and energy are main metrics used to forward the sensed data toward the SINK node and then to internet to be analyzed. While the actuating data can be forwarded using the history of sending sensed data in order find their way to the destination specified by IOT application.

Acknowledgement and error check are not essential to be achieved by the network layer, since it is one of MAC layer task because this layer is the last layer dealing with the packet. Mobility of nodes must be supported and efficiently handled by using the geographical locations of node during the sending of RREQ and RREP messages to the stationary neighboring nodes. Speed is an important factor that affects the performance but other metrics must be taken into account such as link quality and energy.

REFERENCES

- Boulis, 2009, *Castalia: A Simulator for Wireless Sensor Networks and Body Area Networks*, National ICT Australia Ltd, Australia.

- E. Al-Fagih, 2013, *A Framework for Data Delivery in Integrated Internet of Things Architecture*, PhD thesis, Queen's University Kingston, Canada, April.

- Varga, 2003, *OMNeT++ Discrete Event Simulation System, User Manual*, Version 2.3b1, February 11.

- D. Patel, et al., 2013, *Energy Aware and Link Quality Based Routing in Wireless Sensor Networks under TinyOS-2.x*, International Journal of Modern Engineering Research (IJMER), Vol.3, Issue.3, May-June, pp-1357-1365.

- H. Farooq and L. Tang Jung, 2013, *Energy, Traffic Load, and Link Quality Aware Ad Hoc Routing Protocol for Wireless Sensor Network Based Smart Metering Infrastructure*, International Journal of Distributed Sensor Networks Volume 2013 , 13 pages.

- H. Su, et al., 2013, *MAEB: Routing Protocol for IOT Healthcare*. Scientific research, Advances in Internet of Things, 3, 8.
- H. Yang and S. Pan, 2013, *Modeling and Analysis of IOT Real-Time System Using TCPN*, Information Technology Journal 12(9), 1707-1716.
- J. Gubbi, 2013, *Internet of Things (IOT): A Vision, Architectural Elements, and Future Directions*, Future Generation Computer Systems 29.7, 1645-1660.
- K. Machado, et al., 2013, *A Routing Protocol Based on Energy and Link Quality for Internet of Things Applications*, Sensors, 13, 1942-1964.
- M. Rondinone, et al., 2008, *Designing a Reliable and Stable Link Quality Metric for Wireless Sensor Networks*, Proceedings of the workshop on Real-world wireless sensor networks, ACM.
- O. Chipara, 2010, *Towards Real-Time Wireless Sensor Networks*, PhD Dissertation, Department of Computer Science & Engineering - Washington University, Saint Louis, Missouri, may.
- O. Mazhelis, et al., 2013, *Internet of Things Market, Value Networks and Business Models: State of the Art Report*. Jyvaskyla University Printing House, Finland.
- P.M Sridevi, et al., 2013, *Energy Efficiency by Utilizing Link Quality and Loop Breaking In WSN*, International Journal of Engineering and Advanced Technology (IJEAT), Volume-2, Issue-5, June.
- R. Baumann, et al., 2007, *A Survey on Routing Metrics*, TIK Report 262, Computer Engineering and Networks Laboratory, Switzerland.