2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC)

EC-MRPL: An energy-efficient and mobility support routing protocol for Internet of Mobile Things

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Abstract—**Internet of Mobile Things (IoMT) is a new paradigm of the Internet of Things (IoT) where devices such as sensors, robots, unmanned aerial vehicles (UAV) and cars, are inherently mobile. While mobility enables innovative applications and allows new services, it remains a challenging issue as it causes disconnection of nodes and intermittent connectivity, which negatively impact the network performance; namely data loss, large handover delay and application functionality failures. In this paper, we propose a new energy efficient and mobility aware routing protocol named EC-MRPL based on the well-known Routing Protocol for Low power and Lossy Networks (RPL standard). Unlike RPL which is designed for low resources networks with basically static devices, the proposed protocol enables to better conserve the energy and sustain the connectivity of mobile nodes. EC-MRPL integrates an enhanced mobility detection method and a novel point of attachment prediction and replacement strategy aware of the resources constraints. As such, EC-MRPL overcomes and mitigates problems caused by mobility. Obtained simulation results using Cooja/Contiki show that EC-MRPL outperforms both the RPL and the MRPL protocols in terms of handover delay, data loss rate, signaling cost and energy consumption.**

Keywords*—*Internet of Mobile Things, 6LoWPAN, Cross-layer design, Micro-Mobility support protocol, RPL.

I. INTRODUCTION

We have been witnessing the emergence of the Internet of Things (IoT) [1]. A host of IoT applications require the appropriate handling of the mobility of the connected devices. Such a requirement find an interest to use Wireless Sensor Networks (WSNs) [2][3] based on the 6LoWPAN technology [4][5]. In fact, the IoT has an importance in our everyday life for many tasks [6]. Its concept consists of integrating some embedded computing devices within the Internet infrastructure. IoT presents a reality to follow the advanced technologies in communication, which make it ubiquitous to all smart users and environments. The 6LoWPAN standard has eased the deployment of IoT as it offers many benefits such as scalability, flexibility, end-to-end connectivity and many others.

Mobility allows many advantages in terms of flexibility, introducing more services, and then enlarging IoT' application domains [7]. However, mobility induces some challenging issues that need to be appropriately solved such as intermittent connectivity of mobile nodes and disconnection of nodes. The major problem caused by these disconnections concerns data losses and transmission delays [8]. Therefore, it is crucial to deal with mobility through finding an alternate attachment point in a brief and bounded time, in order to overcome the encountered issues and ensure continuous connectivity and communication with mobile nodes (MNs).

The design of a suitable mobility support protocol for IoT remains a serious and challenging issue due to the devices limited resources, the unpredictable devices' movement and the application requirement in terms of the Quality-of-Services (QoS) [9]. Several protocols are already proposed in the literature but without considering all constraints particularly the energy consumption. Besides, they present tacit inefficiencies with regards to the handover delay and the data loss [10]. Energy consumption is mainly related to the exchanged control messages (signaling cost), and then it is important to optimize the control process. In addition, the network overload and the large handover delay contribute to affect transmissions and cause data losses.

This paper focuses on the micro mobility support, which is defined as the mobility of nodes within the same network. However, since it may impact the routing path within the network, supporting this kind of mobility is relayed to the routing protocol. The RPL standard presents the most suitable routing protocol for the WSN based on 6LoWPAN technology [11][12]. Nevertheless, it is inefficient and has a rather low reactivity for scenarios with high and frequent mobility. In fact, it is basically designed for static lossy networks and it is a reactive routing protocol for the topology change [13]. As a result, it falls short to being able to avoid node disconnection and data losses. The main limit of RPL is related to the detection of the fast mobility of mobile nodes (MNs) and the recovery of changes before disconnection. Moreover, the significant energy consumption of MNs is not considered in order to increase MNs' lifetime [14].

In this paper, we propose a new routing protocol named EC-MRPL to improve routing process in the context of nodes mobility by predicting nodes movement based on the Received Signal Strength Indicator (RSSI), along with the use of a cross-layer approach. We aim to increase the mobile devices' lifetime and to make the connectivity more robust by introducing a proactive process able to anticipate and predict nodes' movement. To this end, we propose a novel point of attachment replacement strategy, yet a particular attention is given to decrease the energy consumption during the signaling processes.

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The remainder of this paper is organized as follows: *Section II* presents some of the relevant work proposed to improve RPL standard under mobility. In *Section III*, we describe the detail of the proposed EC-MRPL protocol. *Section IV* presents the performance evaluation of the proposed protocol. Finally, *Section V* concludes the paper and suggests further orientations and perspectives.

II. RELATED WORK

This section gives an overview of some existing protocols based on RPL standard to support mobility.

In [15], authors proposed Mobility Enhanced RPL (ME-RPL) to extend RPL. Hence, in order to increase routes stability, ME-RPL proposes to avoid selection the MN as the preferred parent (PP). Then, in order to avoid MN disconnection, ME-RPL uses the periodic sent of DAG Information Solicitation (DIS) messages based on dynamic interval, to request sending DAG Information Option (DIO) messages. These ones are used to reconnect in case of loosing connection.This solution outperforms RPL in terms of the route stability. Nevertheless, authors does not consider some important parameters such as: the handover delay, the signaling cost, and the energy consumption.

In the context of vehicular networks, authors in [16] studied performances of RPL with some adaptations. First, they proposed to disable the DIO trickle timer, because it was not suitable for frequent topology change. Second, they suggested to improve the re-activity by assessing immediately the link quality and updating the routing graph. Third, they proposed to carry the parent's ID in the DIO message in order to detect and avoid the loop problem. In the same way, authors in [17] proposed GI-RPL protocol as an extension of RPL for Vehicular Ad hoc Networks (Vanet). GI-RPL was based on the node localization to deal with the frequent dynamic topology. Localization was obtained through distance to sink and direction of the vehicle. Besides, this solution was based on an adaptive DIO period instead of the trickle timer, for better performances. These solutions provided an improvement in terms of the packet delivery ratio, and the packet delay. However, they did not consider the energy constraint because of the vehicular networks characteristics.

In [18], authors proposed MoMoRo to support mobility with RPL standard. MoMoRo used a mobility detection method based on the number of re-transmission. Its process consisted in collecting information from neighbors when a node mobility was detected. Then, it used a fuzzy estimator to estimate links quality and to provide the robust link for the new attachment of the MN. Nonetheless, this protocol was a reactive solution and needed more handover delay and more signaling cost.

In [19], authors proposed new protocol called Co-RPL. This solution was based on Corona mechanism, to localize nodes relatively to the DAG root and to detect nodes movement. However, this solution can't resolve problems caused by mobility such as MN disconnection and reaction to recover it.

In [20], authors proposed MRPL protocol to deal with mobility based on a proactive process. Although this proposition presented a good contribution and succeeded to improve some needed performances, some enhancements were still needed. For example, authors weren't take into consideration to the energy consumption, mainly for the MN, which was very involved to react face to the mobility. In addition, the periodic sent of messages used for the mobility detection make it very costly, both for the overhead and the energy consumption. Moreover, the huge signaling cost between the MN and its PP caused an overload, which avoided transmitting all transferred data packets and caused their losses. Furthermore, the disconnection time problem was still posed. In fact, with MRPL, the MN didn't send data packets during the handover delay, however, a node connected and forbidden to send messages was considered as a disconnected node. This protocol was chosen to be compared with our proposed protocol.

III. EC-MRPL: MOBILITY SUPPORT PROTOCOL

The main aim of EC-MRPL protocol is to reduce the MN energy consumption while providing the seamless connectivity in order to avoid data losses and to reduce the handover delay. keeping MN energy helps it to increase its lifetime, because of its hard redeployment, and in order to keep the proper functioning of the application that based on the MN. EC-MRPL is an extension of the RPL routing protocol for Lossy Networks to support node and micro mobility. The main idea consists of introducing a proactive process to recover issues caused by the topology change related to the node mobility. Besides, it consists to reduce the MN involvement and the control messages overload, because they impact on the energy consumption and the data transmission.

A. *Modification in the RPL protocol*

First, EC-MRPL is based on the integration of a proactive process in the RPL standard to deal with micro and node mobility, which focuses on two steps: the movement detection and the new attachment prediction before losing the connectivity. The proactive process helps to avoid or reduce disconnection time and data losses during the handover process.

Second, the MN is excluded from the route path, to avoid the route interruption. Thus, it joins the DoDag graph tree only as a leaf node. Thus, it does not need to send DIO messages. This way helps to ensure routes stability and to keep resources of this node in term of overhead and energy.

Third, EC-MRPL is a network based protocol, where the MN is not involved in the mobility support in order to keep and preserve its resources. The idea consists in distributing the energy consumption between different static nodes (SNs). To this end, the MN is relied to a SN called "Associated Node" (AN), which refers to the preferred parent in RPL. This node is responsible to perform: 1) Transfer data to/from the MN. 2) Detect movement of the MN away from its range area. 3) Predict and find another AN for the MN. This point does not only help the MN to reduce its energy consumption, but it also helps to reduce the overhead between the MN and its AN. Hence, it helps it to transfer more data packets through avoiding the overload. In addition, to ensure continuous connectivity, the MN is disconnected from its current AN, only after receiving confirmation to be connected with the predicted AN.

Fourth, at the beginning, the MN performs the same process as the RPL to join a PP in the DoDag graph tree,

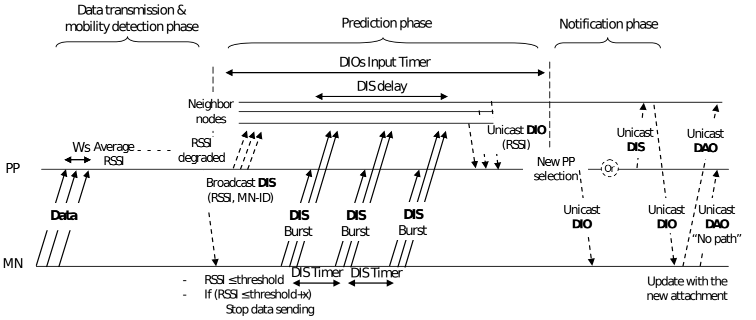


Fig. 1. Timing diagram of EC-MRPL protocol

based on the objective function. Then, during movement, the nearest SN will be considered to select the new AN.

Fifth, some fields in ICMPv6 control messages (DIS, DIO) are added, to be considered to deal with mobility such as the RSSI to carry the average RSSI value and flag to distinguish between each used message.

Sixth, upon the MN receives a new attach message, it immediately sends DAO messages to update the backward route. It does not schedule it as defined by the RPL standard. Two DAO types are used: the first is sent to the new AN, in order to add the new route availability for the MN. And the second ”no-path” is sent to the previous AN, in order to delete the route used by the MN through the previous attachment. These immediate update helps to avoid disconnection time, and avoid data losses.

B. *EC-MRPL protocol description*

When a MN moves away from the range of its attachment point, EC-MRPL follows some steps as illustrated in fig.2 to deal with this change.

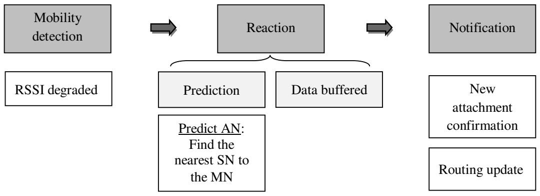


Fig. 2. The different steps of EC-MRPL protocol

EC-MRPL process is ensured based on the existing ICMPv6 control messages used by the routing protocol RPL, with some added fields.

1) Detection and transmission phase: During the transmission data, the AN computes periodically the average RSSI value with the MN, through receiving data packets. When it detects that this value is degraded and reached a predefined threshold, it deduces that the MN will go away from its coverage area. Thus, a mobility is detected and the next phase will be triggered. Then, during the handover process, the current AN keeps the connection with the MN and reception of data packets. Besides, it continues checking RSSI value, to notify the MN to stop sending data in case of RSSI reaches $(threshold - x)$.

In EC-MRPL, the AN is responsible to detect the node mobility. Unlike MRPL, the MN doesn’t need to receive signaling messages to detect mobility during the transmission phase. On the one side, the MN may keep its energy. On the other side, this way reduces exchanged signaling messages between the MN and its AN, which avoid overload that causes the loss of data packets.

2) Reaction and prediction phase: After mobility detection, EC-MRPL pass to the reaction phase, which focuses on the prediction of a new AN based on the RSSI parameter. This phase is performed by the current AN, in order to keep resources of the MN, mainly by reducing reception of messages that needs more energy consumption. Besides, it is performed before disconnection of the MN, in order to quickly recover the handover process and to provide a continuous MN connectivity.

As illustrated in Fig.1, when the AN detects the signal degradation with the MN, it broadcasts DIS messages $(flag = 1)$ carried the computed RSSI and MN-ID fields. Then, it triggers a timer (DIOS_Input) to wait receiving Unicast DIO messages $(flag = 2)$ from other SNs that detect the MN. These DIS messages are received by the MN and neighbors SNs. On the one hand, receiving this DIS, the MN checks the received RSSI:

1) $RSSI \leq threshold$: The MN broadcasts DIS messages $(flag = 2)$ for three times through a timer (DIS_timer), in order to be detected by the SNs.
2) $RSSI \leq threshold - x$: The MN stops sending data packets to avoid data losses, because it is in the border of the average area of its current AN.

On the other hand, SNs receiving DIS $(flag = 1)$ from the AN start detecting the MN according to the received ID. Then, each SN computes the average RSSI through received burst DIS $(flag = 2)$ from the MN. Next, each one sends a unicast DIO $(flag = 2)$ carried the computed RSSI to the current AN. The current AN also receives DIS $(flag = 2)$ from the MN and computes the average RSSI, in order to be considered in the best RSSI selection.

Furthermore, after (DIOS_Input) timer expiration, the current AN compares all collected RSSI values in order to select the highest value that refers to the nearest SN to the MN. This selected SN presents the predicted AN, which may remains the same current AN.

3) Notification phase: After the prediction phase, the current AN triggers the notification phase, in order to perform the required update of the path routes. On the one hand, in the case of the AN remains unchanged, this node just notifies the MN about the process completion. On the other hand, in case of the predicted AN is a new node, it will be informed by the current AN. Then, receiving this notification, the predicted AN sends a unicast DIO message ($flag = 1$) to the MN, in order to request it to be its new attachment. Thus, the MN starts by updating its parameters (rank, PP, default route to the root node). Next, it sends in back a two immediate DAO messages to the new predicted AN and the previous AN, in order to update its backward path route, by adding and removing path route respectively.

Through this way, the MN is disconnected from its previous AN only after its new attachment with the predicted AN, which helps to avoid disconnection time and data losses in consequence.

4) Mobile node involvement: In such case, when the prediction process is failed, the MN is required to be involved to support mobility and find its new attachment. This failure may be caused by the lost of some signaling messages used to support mobility, or the inability to detect the MN when it moves. In fact, at the beginning of each handover process, when the MN receives DIS message ($flag = 1$) from its AN, a timer is triggered. Then, the MN will be involved in case of the timer expires without achievement of a new attachment. Hence, the MN broadcasts DIS messages ($flag = 0$) to request receiving trickle DIO messages ($flag = 0$) from SNs in its range. Trickle DIO helps the MN to be attached with the sender of the received DIO.

This process is required to be repeated, until the reattachment of the MN and return to the transmission phase.

IV. PERFORMANCE EVALUATION

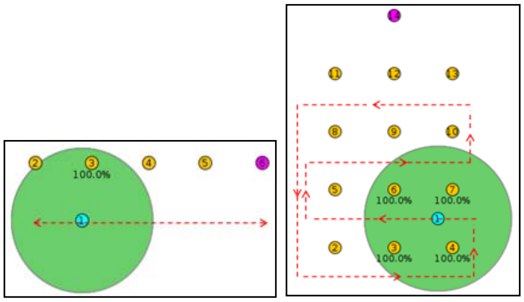
In this section, we discuss the performance evaluation of the proposed EC-MRPL protocol through different simulation scenarios while comparing to RPL standard, and MRPL protocol [20].

A. Simulation setup

We used Contiki IPv6/6lowpan platform and the open-source implementation of RPL named ContikiRPL that is widely used [21]. Then, as simulation tool, we used Cooja simulator, which is the discrete event simulator in the Contiki OS [22].

In order to compare performances of the proposed EC-MRPL protocol with MRPL, we implemented both of them based on the ContikiRPL. Then, we introduced three distinguish entities: MN, SN and ROOT node. Scenarios are illustrated in Fig.3. A MN is used to send periodically data packet towards the root node, through SNs. In scenario (a), the MN moves horizontally from the one corner to the other. Whereas, in scenario (b), the MN moves over the network according the red lines. The simulation parameters are given in the table I.

We focus on four performance metrics: signaling cost, energy consumption, handover delay, and packet delivery ratio.



(a) (b)

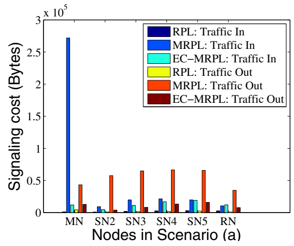
Fig. 3. Two simulated scenarios: a) and b)

TABLE I. SIMULATION PARAMETERS

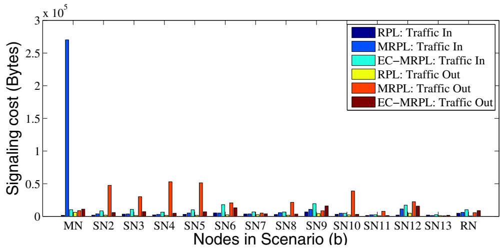
Data Rate	30 packet/s
Traffic type	CBR
Speed	2 m/s
Transmission range	50 m
Mobility model	Random Walk model
Simulation time	900 s
Threshold RSSI	-90 dBm

B. Signaling cost

The signaling cost is defined by the bytes number of exchanged signaling messages related to the mobility support (DIS, DIO and DAO ICMPv6 messages).



Scenario (a)



Scenario (b)

Fig. 4. The signaling cost for each node in both scenarios a) and b)

The main aim of EC-MRPL is to reduce energy consumption of the MN. To this end, it is crucial to reduce its signaling cost, mainly the reception messages that needs more energy consumption. In addition, it is necessary to reduce exchanged messages between the MN and its AN in order to avoid overload to allow transferring data packets. Figure 4 presents the signaling cost for each node in both scenarios a) and b) with different incoming and outgoing messages (Traffic In/Out). Following this figure, the signaling cost is significantly reduced by EC-MRPL compared to MRPL what ever the node is. But, it is with small increase relative to RPL, because of the signaling needed to support mobility. Furthermore, we notice that the signaling cost is very important for the MN with MRPL protocol compared to other kind of nodes. EC-MRPL reduces at 23 and 27 times the signaling cost for scenarios a) and b) respectively. These results can be explained because of MRPL is a host based protocol, where the MN is very involved to support mobility. In addition, the mobility detection process in MRPL is based on periodic control messages. Whereas, EC-MRPL is a network based protocol where the AN is responsible to perform the needed process to deal with mobility. Thus, through this way, the signaling cost is shared between different SNs, since the AN is changed during the MN movement. Moreover, EC-MRPL uses DIS message instead DIO because it is with low size.

C. Energy consumption

The energy consumption has an important impact on the lifetime of nodes. It is mainly related to messages transmission and reception, processing (CPU) and idle state (LPM) or overhearing. EC-MRPL is focused mainly to conserve the energy consumption for the MN, as we have noted previously.

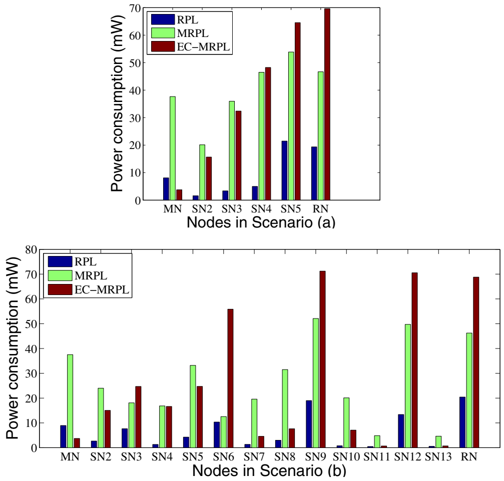


Fig. 5. energy consumption for each node

The cost of reception signaling messages for the MN is significantly reduced, and consequently the energy consumption is reduced with EC-MRPL compared to both RPL and MRPL. As presented in fig.5, it is about $3.79mW$ and $3.72mW$ by EC-MRPL compared to $37.66mW$ and $37.53mW$ by MRPL and $8.11mW$ and $8.93mW$ by RPL respectively for scenario (a) and (b). However, the energy consumption is relatively approached for other kind of nodes for both EC-MRPL and MRPL protocols. We note also that the Root Node (RN) consumes more energy by EC-MRPL ($68.8mW$ for scenario (b)) than by RPL and MRPL (respectively $20.42mW$ and $46.24mW$ for scenario (b)). This consumption increase for SNs and RN is caused by the energy dissipated to transfer data packets (not for the overhead signaling), since the network has succeeded to transfer more data packets using EC-MRPL (discussed below). Moreover, we have observed that nodes nearest to the RN consumes more energy than other nodes. It is about $71.23mW$ and $70.56mW$ for SN9 and SN12, compared to $15.05mW$ and $24.69mW$ for SN2 et SN3 with EC-MRPL in scenario (b). This result is explained as follows: Nodes nearest to the RN are more involved in the routes path, which they represent the most nodes that contribute in transferring data packets to the RN. Then, as illustrated in fig.5, the energy consumption of SNs with RPL represents the least compared to MRPL and EC-MRPL protocols, because SNs doesn't contribute to support mobility and there is less data packets transferred. Thus, they keep their energies, but, they can't provide a continuous connectivity.

Therefore, following these results, with EC-MRPL the energy consumption of SNs is efficient with consideration to the data transferred within the network. Besides, this protocol helps the MN to keep its energy and to provide a highest lifetime required to the proper application functioning.

D. Handover delay

The Handover delay is the needed delay to reestablish a new connectivity during movement. This delay is measured through the needed delay between the last packet sent in the previous attachment and the first packet sent in the new attachment. Thus, a MN that doesn't send data is considered as a disconnected node, even it is connected.

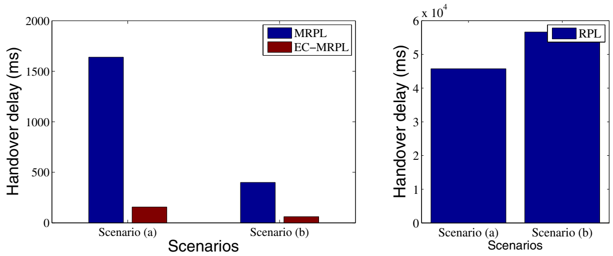


Fig. 6. Simulation results of the handover delay

Both MRPL and EC-MRPL protocols are based on a proactive process to deal with mobility. Thus, they succeed to reduce the handover delay compared to the RPL standard. However, MRPL can't avoid the disconnection of the MN. As illustrated in fig.6, the handover delay is about $156.25ms$ and $60.65ms$ for our proposed protocol compared to $1639.06ms$ and $399.6ms$ for MRPL and $45737ms$ and $56640ms$ for RPL, respectively for scenario (a) and (b).

Our proposed protocol provides a continuous connectivity, because, the MRPL protocol requires the MN to stop sending data during the handover process, as soon as, it detects an unreliable link. Whereas, with EC-MRPL protocol, the MN continues sending data during the handover process, and it is stopped only when it receives notification carried an RSSI value less or equal to $-93dBm$ $(threshold - x)$, which means that the MN is in the border of the range area of its AN. In addition, according to EC-MRPL, we observe that in scenario (a), among 44 handover, the MN is stopped to send data packets only for 3 times. And for scenario (b), among 32 handover, it is stopped only for 5 times.

E. Packet Delivery Ratio

The Packet Delivery Ratio (PDR) is the ratio of the total number of delivered packet to the total number of sent packets.

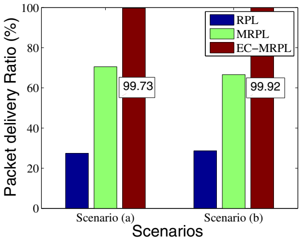


Fig. 7. Simulation results of the Packet Delivery Ratio

As illustrated in fig.7, the PDR by EC-MRPL is very improved compared to both RPL and MRPL protocols. It is relatively near to 100% for both scenarios. Unlike RPL and MRPL, whose PDR is in the average of 27% and 70%, respectively. This result is ensured by providing a continuous connection and the reducing of signaling cost between the MN and its AN as used by the MRPL protocol. A great signaling cost causes an overload and congestion, which rejects data packets and avoids them to be transferred.

The buffering data packets in such handover process, helps to avoid data losses. This strategy is used by MRPL and EC-MRPL. However, it wasn't good elaborated by MRPL, because some data packets are falsely prevented to be sent. Consequently, the MN can't succeed to transfer more packets. For example, in scenario a), MN uses to send only 8792 packets with MRPL protocol. Whereas, it sends 9361 packets with EC-MRPL.

V. CONCLUSION AND PERSPECTIVES

We proposed a new routing protocol to support micro mobility named EC-MRPL for the Internet of Mobile Things (IoMTs). Firstly, EC-MRPL has the aim to provide a continuous connectivity in order to keep MNs reachable regardless their whereabouts. The proposition is based on a proactive protocol to predict new attachment of MNs before their disconnection. This process is relayed on the cross-layer information (RSSI) and the icmpv6 messages of RPL standard based on some predefined flags. Secondly, EC-MRPL takes consideration to the strict constraints of our interesting network, in order to fulfill requirements and to provide needed performances. Thus, the main idea with supporting mobility consists of reducing the MN involvement to keep its energy, and sharing resource dissipation between different ANs. Besides, it is focused on using less exchanged signaling messages to avoid overload and provide the ability to transfer more data packets.

We implemented and integrated EC-MRPL protocol into the ContikiRPL. Then, through some scenarios simulation, we proved that our proposed protocol overcame encountered problems with RPL standard to support micro mobility of nodes. In addition, we proved that EC-MRPL outperformed MRPL protocol, particularly in providing seamless connectivity and reducing signaling cost, which impacts on the energy consumption of the MN and the data packets transmission (EC-MRPL provide a PDR nearly to the 100%). As a future work, it would be interesting to more study the prediction method, since RSSI may be affected in indoor environment and presence of some obstacles.

REFERENCES

[1] A. J. Jara, S. Varakliotis, A. F. Gmez-Skarmeta, P. T. Kirstein: ”Extending the Internet of Things to the Future Internet through IPv6 support”. J. of Mobile Information Systems V10, iss1, pp3-17, 2014.

[2] Jennifer Yick, Biswanath Mukherjee, Dipak Ghosal, ”Wireless sensor network survey”, International Journal of Computer and Telecommunications Networking, Vol. 52, Issue 12, pp. 2292-2330, 2008.

[3] D. Culler, D. Estrin and M. Srivastava, ”Overview of Sensor Networks”, IEEE journal of Computer Society, vol. 37, no. 8, pp 41-49, august 2004.

[4] Zach Shelby, Carsten Bormann, ”6LoWPAN: The Wireless Embedded Internet”, book, Internet Engineering Task Force (6LoWPAN-WG), 2009.

[5] Md.S. Hossen, A.F.M.S. Kabir, R.H.Khan and A. Azfar, ”Interconnection between 802.15.4 Devices and IPv6: Implications and Existing Approaches”, IJCSI, Vol.7, Iss 1, N.1, Jan 2010.

[6] J.A. Stankovic, A.D. Wood, T. He, ”Realistic Applications for Wireless Sensor Networks”, Springer Theoretical Comp Sci, pp 835-863, 2011.

[7] Luís M. L. Oliveira, Amaro F. de Sousa and Joel J. P. C. Rodrigues. ”Routing and mobility approaches in IPv6 over LoWPAN mesh networks”, IJCS, Volume 24, Issue 11, pp 1445-1466, November 2011.

[8] L.Bartolozzi, F.Chiti, R.Fantacci, T.Pecorella & F.Sgri lli, ”Supporting monitoring applications with mobile Wireless Sensor Networks: The eN Route forwarding approach”, IEEE International Conference on Communications (pp. 5403-5407), Ottawa, Canada, June 2012.

[9] M. Dohler, T. Watteyne, T. Winter, D. Barthel, ”Routing Requirements for Urban Low-Power and Lossy Networks”, RFC 5548, may 2009.

[10] Maha Bouaziz, Abderrezak Rachedi, ”A survey on mobility management protocols in Wireless Sensor Networks based on 6LoWPAN technology”, Elsevier Journal of Computer Communications, Volume: 74, pages: 3-15, 2016.

[11] Olfa Gaddour, Anis Koubaa, ”RPL in a nutshell: A survey”, ELSEVIER Journal of Computer Networks, pp 3163-3178, 2012.

[12] Ghada Glissa, Abderrezak Rachedi, Aref Meddeb, ”A secure routing protocol based on RPL for Internet of Things”, IEEE Globecom, Washington, DC USA, 2016.

[13] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, ”RPL: IPv6 Routing Protocol for Low Power and Lossy Networks”, IETF Request for Comments 6550, March 2012.

[14] Oana Iova, Fabrice Theoleyre, Thomas Noel, ”Using multiparent routing in RPL to increase the stability and the lifetime of the network”, Elsevier journal of Ad Hoc Networks, pp 45-62, 2015.

[15] I. El Korbi, M. Ben Brahim, C. Adjihy and L. Azouz Saidane, ”Mobility Enhanced RPL for Wireless Sensor Networks”, IEEE Third International Conference on the Network of the Future (NOF), Gammarth, Tunisie, 21-23 Nov. 2012.

[16] K.C. Lee, R. Sudhaakar, L. Dai, S. Addepalli, and M. Gerla, ”RPL under mobility”, In proc. of 2012 IEEE Consumer Communications and Networking Conference (CCNC), Las Vegas, NV, USA, January, 2012.

[17] B.Tian, K.M.Hou, H.Shi, X.Liu, X.Diao, J.Li, Y.Chen, J.P.Chanet, ”Application of modified rpl under vanet-wsn communication architecture”, Fifth (ICCIS), 2013 pp. 1467-1470. doi:10.1109/ICCIS.2013.387.

[18] JeongGil Ko and Marcus Chang, ”MoMoRo: Providing Mobility Support for Low-Power Wireless Applications”, IEEE Systems Journal, Volume:PP , Issue: 99, ISSN : 1932-8184, pp 1-10, mars 2014.

[19] O.Gaddour, A.Koubaa, R.Rangarajan, O.Cheikhrouhou, E.Tovar, M.Abid, ”Co-rpl:Rpl routing for mobile low power wireless sensor networks using corona mechanism”, 9th IEEE International Symposium on Industrial Embedded Systems (SIES), pp.200-209, 2014. doi:10.1109/SIES.2014.6871205.

[20] H. Fotouhi, D. Moreira, M. Alves, ”mRPL: Boosting mobility in the Internet of Things”, ELSEVIER Journal of Ad Hoc Networks 26 pp 17-35, 2015.

[21] J. Ko, J. Eriksson, N. Tsiftes, S. Dawson-Haggerty, A. Terzis, A. Dunkels and D. Culler, ”ContikiRPL and TinyRPL: Happy Together”, IPSN11, April 1214, 2011, Chicago, Illinois.

[22] Anuj Sehgal, ”Embedded Operating Systems, part II the Contiki OS”, Operating Systems (320202), 30 March 2011.