An Energy-Efficiency-Oriented Routing Algorithm over RPL

Cheng-Yen Liao#1,Lin-Huang Chang #2, Tsung-Han Lee#3, Shu-Jan Chen*4

#Department of Computer Science, *National Taichung University of Education, Taichung, Taiwan*

[1]log77456@gmail.com, [2]lchang@mail.ntcu.edu.tw, [3]thlee@mail.ntcu.edu.tw,

* Department of Information Technology, *Overseas Chinese University, Taichung, Taiwan*

[4] sjc@ocu.edu.tw

***Abstract*—** The wireless sensor network is a popular research issue for decades. The smart device development issue and the Internet of Thing (IoT) are the most popular research topics recently. The IETF Workgroup proposed the IPv6 Routing Protocol for Low power and Lossy Networks (RPL),as shown in the RFC 6550, in March 2012 to define the structure and parameters of the RPL. According to RFC 6550, the RPL routing only considers single condition, (reliability or energy) to conduct routing. If RPL only considers the reliability, nodes will suffer from uneven energy. If it only considers energy, nodes will suffer from the rise of packet loss ratio. In order to achieve maximum efficiency, routing decision is important to RPL. This paper proposes a energy-oriented routing decision algorithm to improve RPL routing decision conditions with an attempt to reach averaged overall network energy consumption and therefore prolong the node survival time.

***Keywords*—** IPv6 Routing protocol for Low pow er and Lossy networks(RPL)、IPv6 over Low pow er Wireless Personal Area Networks,Wireless Sens or Network(6LOWPAN) 、 IPv6.

1. Introduction

The wireless sensor network is a popular research issue for decades, the main research topics are focus on energy saving, such as sleep scheduling mechanism、Selection of the best route both are design for energy-saving , because 6Lowpan are new approach different with traditional wsn, such as AODV、OLSR was widely used on routing protocol, and both of then would not support IP architecture, therefore it unable be applied to 6Lowpan，In 2009, Routing Protocol for Low-Power and Lossy Network (RPL) designed by the IETF Workgroup，In order to suitable for low power consumption, computing power and limit memory embedded systems, and published in March 2012, RFC 6550 [1]，the structure and parameters of clear norms and definitions about RPL. In a low-power and lossy wireless sensor network environment, it is a big challenge to how to complete the routing maintenance in the lowest costs, RPL in the design that is taken into routing damaged（mobility node、Lack of energy）. Therefore, when routing is damaged, it can switch the backup routing , such as multipath mechanism [2] in wsn.

According to RFC6551, the RPL routing only considers single condition, (reliability or energy) to make routing. If RPL consider only reliability , node suffer from uneven of energy. If consider only energy , node suffer from rise of packet loss ratio. In order to achieve maximum efficiency, routing decision it is important to RPL, therefore in this project propose to design a energy-oriented routing decision algorithms to improve RPL routing decision conditions, in an attempt to reach averaged overall network energy consumption and prolong node survival time. In the other head we also propose the RPL routing performance optimization base on sink location.

The goal is design a energy-oriented routing decision algorithms to averaged overall network energy consumption and prolong node survival time, which reduce energy consume on management and maintenance. We use the COOJA network simulator to simulate RPL, and analyze of energy consumption, to improve algorithm performance. In addition we also analysis of sink configuration location and the impact of energy. Also, we hope to implement RPL routing protocol on WSN and combine RPL and IPv6 complete IoT applications.

2. Related research

In IoT architecture the IPv6 network packets unable transmitted on 802.15.4 networks, because Ipv6 MTU is different than 802.15.4 , Therefore the packet need to fragmenting and recover, applied to IP packet architecture ,routing protocol will be different，in this chapter will focus on IoT (Internet of Things) and RPL.

2.1 IoT(Internet of Things)

Internet of Things (IOT) concept from the International Telecommunication Union(ITU) Internet Reports 2005: The Internet of Things[3], means that the future society will becoming "ubiquitous network society" ,The convenience of the modern Internet technology, people in addition to connect with the Internet through desktop computers, also through mobile phones, notebook, even Smart Object , all can be connect to Internet， in the past connect to machine only use of "Human to Machine"(H2M)，but can be easily reached Machine to Machine(M2M) through the Internet, Internet of Thing (IoT) as a new concept of network architecture, through the Internet can easily link and control the electronic products around us, such as figure 1, the IoT will Innovation enable forms of collaboration and communication between people and things, Information and communication technologies （ICT）, through this technology we will be able to connect to any object at any time, any where.

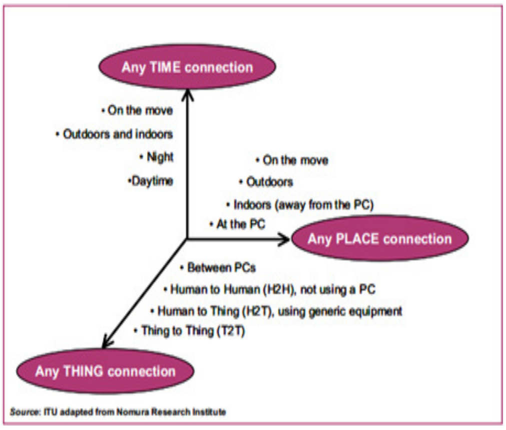

Figure 1.IoT Applications

2.2 RPL(IPv6 Routing Protocol for Low power and Lossy Networks)

The wireless sensor network is a popular research issue for decades, the smart device development issue is popular recently ,and the Internet of Thing(IoT) is the most popular research topic, The IETF Workgroup proposed the IPv6 the Routing Protocol for Low power and Lossy Networks (RPL), and standard the RFC 6550 in March 2012, define the structure and parameters of the RPL.

Such as figure2. RPL builds Directed Acyclic Graph (DAG) topology to establish bidirectional routes and reduce topology complexity for LLNs. Provided traffic types covers multipoint-to-point, point-to-multipoint, and point-to-point. The traditional WSN routing only provide point to point of communication, RPL can immediate Route conversion of Signal instability ensure that routes are reachable.

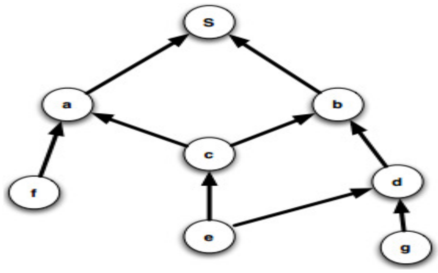

figure 2. DODAG approach

RPL provides a mechanism to disseminate information over the dynamically-formed network topology.

The control message DIO(DODAG Information Object) 、 DAO(Destination Advertisement Object) 、 DIS(DODAG Information Solicitation) ,respectively. each node only needs to communicate with neighboring nodes maintenance, Information

Option (DIO) messages, containing information about the node rank, objective function, IDs, etc. They are Periodic Broadcast by each node to maintains the DODAG.

3. Propose

This paper proposed energy-oriented routing decision algorithms base on IETF RFC 6650 RPL Routing Protocol, according to RFC 6550 RPL routing network topology is a Destination Oriented Directed Acyclic Graph (DODAG)，transfer data to the Root processing and non routing loop, Routing decisions according to Rank and Object Function(OF)，Which Rank is designed to avoid loop generation parameters, OF is defined routing decisions conditions。IETF RFC6551[4] define how to apply the Object Function (OF) the choice of routing decisions, which contains the Node Metric and Link Metric，The Node Metric means for the individual node status, it contains (node status, node energy, node hops)，Link Metric to indicate routing quality, it contains

ETX-Expected 、 Transmission Count 、 Throughput 、Delay), route selection criteria can be explicitly defined by OF，But single DODAG unable to apply more than one metric only choose one as the routing Metric.

Because link quality will seriously affect network connectivity, to avoid undesirable routing instabilities resulting in increased latencies and packet loss. The ETX[5] is the number of transmissions a node expects, such as Proposition 1, where Df is the measured probability that a packet is received by the neighbor and Dr is the measured probability that the acknowledgment packet is successfully received. Through the ETX values to dynamic comparative stability of the node, when ETX value is low than represents the transmission success rate is higher，therefore priority will be given priority nodes to select the node.

$$ETX = \frac{1}{d_f \times d_r} \quad (1)$$

Because ETX value is the success rate of packet transmission, only the selection of relatively stable node link will cause the energy inequality, Therefore, we propose consideration that the node energy in the RPL routing algorithm, uniform distribution of nodes transmit the amount of data to avoid nodes energy unevenly and extending maximum network lifetime。Reference[6] indicate node depth is also the impact of network lifetime，The closer the Sink node will be responsible for forwarding more data，the closer the the sink node energy need to pay more attention. Therefore, we will be added to the RPL routing algorithm with the node residual energy-aware routing algorithm，the algorithm calculated the ETX values and node residual energy value respectively, and choice the best path，such as figure 3, Node E send data to node A has two paths on link，the algorithm will compare the ETX and Energy respectively, and selection of a stable and adequate energy nodes for data transmission.

Because can not get the node battery on the simulator, therefore, we use energy consumption to calculate the residual energy，COOJA MAC layer is X-MAC[7]，according the reference can get individual state intensity of current consumption，we can use the Proposition2 To calculate energy consumption.

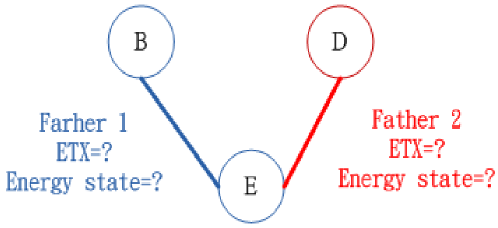

Figure 3. Route selection conditions

$$\text{Energy Consume (in mAh)} = t\_cpu * I\_cpu + t\_radioRX * I\_radioRX + t\_radioTX * I\_radioTX \quad (2)$$

Such as Proposition2, the x representative for individual state algebra，t_x representative for state time，I_x representative for Status consumption current value，by the proposition2 can calculate total energy consumption, via the proposition 3 the residual energy can be calculated.

$$\text{Battery-Energy Consume} = \text{remain energy} \quad (3)$$

The meaning of the node energy and ETX values are different, the node energy behalf battery value, the ETX on behalf of expected number of transmissions, the parameter unable be calculated directly, such as proposition4 ,we design a proposition calculate by Percentage.

$$R = \alpha \frac{\text{ETX}}{\text{Maximum ETX}} + (1-\alpha)(1 - \frac{\text{Remaining Energy}}{\text{Maximum Energy}}) \quad (4)$$

The α is the parameter weighting value, adjust two parameters for the calculation of the proportion.The energy-oriented routing decision algorithms is shown in Figure 4, when there are two nodes A nodes B need to be compared, through the proportion 4 calculated value of R, and return smaller values as a priority to choose the next hop.

```
define   α=0.5;   /* parameters weight */

If (NodeA   &&   NodeB   != Null)
   {
   RA =BestNextHop(Node A );
   RB = BestNextHop(Node B );
   Return   RA<RB ? NodeA:NodeB;
}
   Else Return NodeA;
BestNextHop(Node)
{
   R   =   α   [(ETX)/Maximun_ETX]+(1-
α)[1-(Remain Energy/Maximum_Energy)];
   Return R;
}
```

Figure 4. Energy-oriented routing algorithms

Through the above routing decision algorithm, considerations ETX, remaining energy, and through the weight value assigned to calculate the most suitable node, it can balanced overall routing energy consumption and prolong the overall network lifetime.

4. Result

We use the contiki OS[8] network simulator COOJA[9] network simulator to simulate RPL, and analyze of energy consumption. Contiki is an open source operating system for the Internet of Things. contiki allows tiny, memory-constrained battery-operated low-power systems communicate with the Internet. contiki provides three network mechanisms: the uIP TCP/IP stack, which provides IPv4 networking, the uIPv6 stack,which provides IPv6 networking. Cooja is the Contiki network simulator. Cooja allows simulate large and small networks topology of Contiki motes. Motes can be emulated at the hardware interface behavior, which is slower but allows precise inspection of the system behavior.

Relevant simulation parameters are set as follows in Table 1, the network environments set in the distance Lossy to simulate RPL performance, simulated 4 nodes and 25 node respectively.

Therefore, we confirmed that our proposed Energy Module effectively uniform node energy consumption, in particular to explore whether energy consumption forwarding information, shown in Figure 5 for four nodes topographies which node1 is Sink , responsible for build the overall RPL environment and data collection, the nodes 2,3,4 severally sensing information for general sensing node for transmission.

Parameter	Value
Network Field	300m*300m
Number of Sensor	4、25
Transmission Range	50m
MAC Layer	X-MAC
Routing Protocol	RPL
RPL Mode	non-storing
DIOIntervalMin	3s
DIOIntervalDoublings	20s

Table 1. Simulator parameters

Which due to the limitations of transmission range so node 4 unable directly transfer data to Sink, it need other nodes for data forwarding to Sink. In accordance with the original RPL will be selected based on ETX Link selection stable node for data transfer, but forwarding packets will consume large amounts of energy on node.

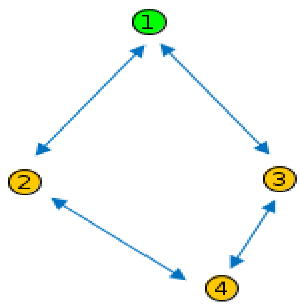

Figure 5. Network topographies

Show in Figure 6 , because node 4 to choose its recent node 3 to forwarding packet to sink，Therefore, node 3 forwarding node 4 packets to sink , Thus node energy consumption more than node 2.

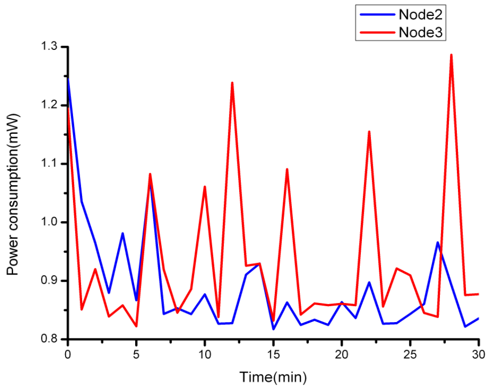

Figure 6. Original RPL node energy consumption

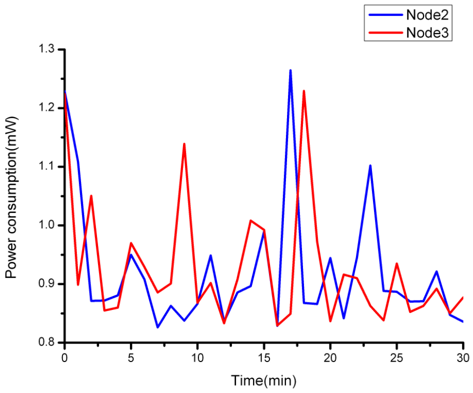

Figure 7. Import Energy module Node energy consumption

Show in Figure 6, Thus node3 energy consumption more than node 2. Import Energy module, the node consumption will effectively homogenize show in Figure 7, forwarding node selection based on the link stability and node energy state, forwarding node selection based on the state of energy state, achieve a uniform overall network energy consumption and enhance the overall lifetime of the network environment.

Data packets need to be around sent Sink for processing and then sent to the Destination，Therefore when the the node distances Sink faraway ,it will cost additional more energy，Therefore, we will study the environment under the same network topology, Sink-side position configuration for the overall energy consumption，We will analysis the average energy consumption and Hop Count overall performance. Simulator results to 25 the number of nodes, distributed in the range of 200m x 200m, RPL topology build achievements，and adjusted the Sink position, Figure 8、Figure 9, respectively, sink on the top and middle. Because Sink adjusted topology environment also differ.

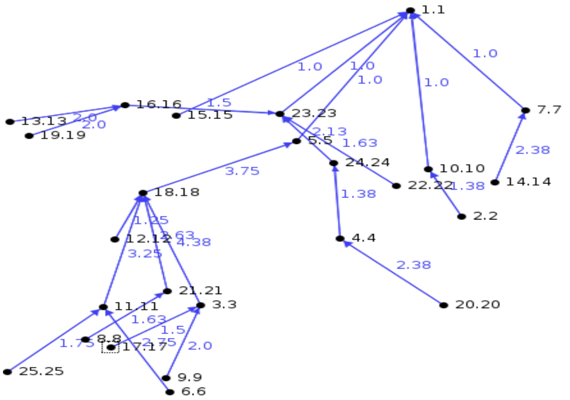

Figure 8. Sink at the top topology

Show in Figure 8 of Sink at the top, RPL will by Sink gradually down to construct a DODAG architecture, when Sink at the top ,all the amount of data sent to the top from the individual nodes, RPL will regularly send Destination Advertisement Object(DAO) to sink by Individual node. Shown in Figure 8, the farthest node 25 and node 6 to be sent to the Sink need 4 Hop relay to the Sink.

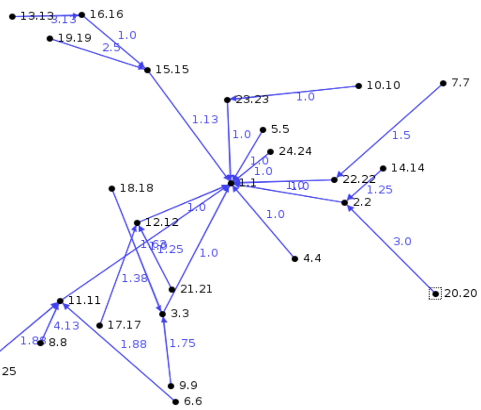

Figure 9. Sink at the middle topology

Therefore, shown in Figure 8, the farthest node 25, node 6 to be sent to the Sink need relay 4 Hop to the Sink, change sink position to middle, it original need 4 Hop reduced to 2 Hop, and overall network data transmission is more uniform, not certain node needs to transfer the transmission of large amounts of data. Average Hop Count reduced from 2.8 to 1.625 hop, the average total energy consumption reduced from 1.17mW to 1.02mW，details data shown in Figure 10 and Figure 11.

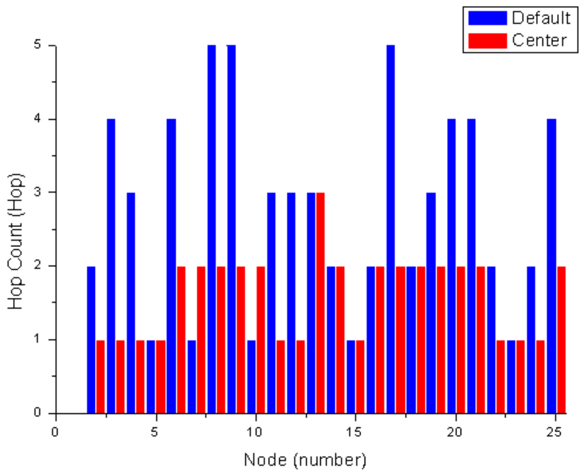

Figure 10. Hop Count Comparison

Simulation results, to change Sink location, the Hop Count average value decreased from 2.8 to 1.625 hop.

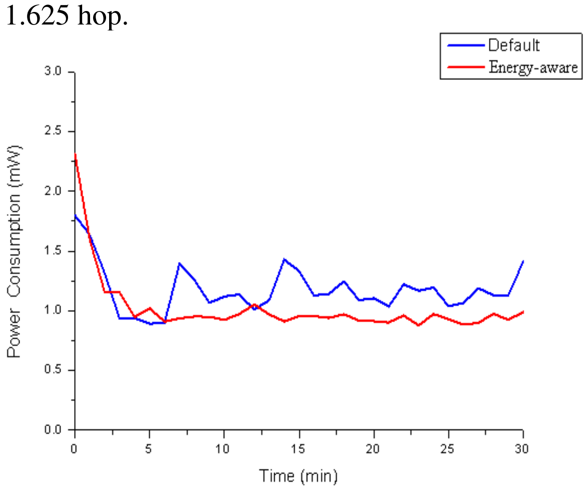

Figure 11 Comparison of the total energy cost

Through the energy-oriented routing algorithm, shown in Figure 11, the average energy cost can reduce energy consumption by about 8%, not only can the average distribution of energy, more prolong overall network lifetime.

5. Conclusions

In this paper, we combined among the most popular research topics Internet of Things (IoT),We focused on the RPL routing under LLN environment to protocol testing and design with energy-aware routing to decide the algorithm, homogenization to consumption the energy of overall node, in order to avoid the energy of black hole which led to declines overall network survival time significantly, and through defining weight ratio to allocate link reliability and node energy to avoid single parameter to affect the routing. In addition, we also simulate to analysis performance of the decide algorithm of the routing that we designed ， to validate homogenized lose of energy node is indeed that the method we proposed, and can improve dispersion the loss of energy effectively, in addition, we also found configure the Sink will have some effect the costs on maintenance the RPL routing by simulation the results of adjustment Sink configure in dynamic, Therefore, we also explore the effect on lose of the energy on differences configuration Sink, and we discovered Sink located in the middle will balance 8% overall lose of energy.

In the future, we will continue to improve the routing decision algorithms and consider to compare with performance analog in a variety environmental, and through embedded development board to run the RPL routing protocols on the embedded device platform, through testing Contiki OS to run RPL routing protocol completely, using IPv6 to transfer the data of each sensor nodes and expect to complete integration of wireless sensor networks combined with the Internet of things.

ACKNOWLEDGMENT

The authors would like to acknowledge the support of the National Science Council of Taiwan, under Contract No. NSC 101-222 1-E-142 -003、NSC-100-2221-E-142-008.

REFERENCES

[1] A. Brandt, J. Hui, R. Kelsey , P. Levis,K. Pister,R. Struik,JP. Vasseur, R.Alexander. RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks .IETF RFC 6550,May 2012.

[2] D. T. Nguyena, , W. Choib, , M. T. Ha, ,H. Choo. Design and analysis of a multi-candidate selection scheme for greedy routing in wireless sensor networks, Journal of Network and Computer Applications, Volume 34, Issue 6, November 2011, Pages 1805–1817.

[3] International Telecommunication Union (ITU), ITU Internet Reports, The Internet of Things, November 2005.

[4] J. P. Vasseur, M. Kim, K. Pister, N. Dejean, and D.Barthel, “Routing Metrics used for Path Calculation in Low Power and Lossy

Networks," IETF RFC 6551 , May 2012.

[5] D.S.J. Couto, D. Aguayo, J. Bicket, and R. Morris. A High-Throughput Path Metric for Multi-Hop Wireless Routing. In MOBICOM, 2003

[6] F. Ren ,J. Zhang ,T. He , C.Lin , R. S.D.K , "EBRP: Energy-Balanced Routing Protocol for Data Gathering in Wireless Sensor Networks", IEEE Transactions on Parallel and Distributed Systems, vol. 22 Issue 12 pp.2108-2125, Dec 2011.

[7] M. Buettner, G. V. Yee, E. Anderson, and R. Han, X-mac: a short preamble mac protocol for duty-cycled wireless sensor networks. In SenSys '06: Proceedings of the 4th international conference on Embedded networked sensor systems, pages 307–320, Boulder,Colorado, USA, 2006.

[8] "Contiki Operating System." [Online]. http://www.sics.se/contiki/

[9] "Cooja Simulator." [Online]. http://www.sics.se/ fros/cooja.php

[10] J. J. P. C. Rodrigues and P. A. C. S. Neves. A survey on IP-based wireless sensor network solutions.International Journal of Communication Systems,2010

[11] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler. Transmission of IPv6 Packets over IEEE 802.15.4 Networks. Internet proposed standard RFC 4944, September 2007.

[12] A. H. Chowdhury, M. Ikram, H.-S. Cha, H. Redwan, S. M. S. Shams, K.-H. Kim, and S.-W. Yoo, "Route-over vs mesh-under routing in 6LoWPAN," presented at the Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly, Leipzig, Germany, 2009

[13] O. Gaddoura, A. Koubâab, RPL in a nutshell: A survey, journal of Computer Networks, Volume 56, Issue 14, 28 ,Pages 3163-3178, Sep. 2012.

[14] J. Eriksson, F. Österlind, N. Finne, N. Tsiftes, A. Dunkels, T. Voigt, R. Sauter, and P. J. Marrón. Cooja/mspsim: Interoperability testing for wireless sensor networks. In Proceedings 2nd International Conference on Simulation Tools and Techniques (SIMUTOOLS'09), Rome, Italy, Mar. 2009.

[15] D. Wang, Z. Tao, J. Zhang, A. Abouzeid, "RPL Based Routing for Advanced Metering Infrastructure in Smart Grid," Proceed-ings of the IEEE International Communications Conference (ICC), Cape Town, South Africa, May 2010.

[16] J. Kim " A 6LoWPAN Sensor Node Mobility Scheme Based on Proxy Mobile IPv6", IEEE Transactions on Mobile Computing, vol. 11 Issue 12 pp.2060-2072, Dec 2012.

[17] "OpenWSN" [Online]. http://openwsn.berkeley.edu/

[18] L. Atzori, A. Iera, and G. Morabito, "The Internet of things: a survey,"Computer Networks, vol. 54, no. 15, pp. 2787–2805, Oct. 2010.

[19] J. Hui and D. Culler, "Ipv6 in low-power wireless networks," Proceedings of the IEEE, vol. 98, no. 11, pp. 1865 –1878, 2010.

[20] E. Baccelli, M. Philipp, and M. Goyal. The p2p-rpl routing protocol for ipv6 sensor networks: Testbed experiments. In Proc. 19th Int. Software, Telecommunications and Computer Networks (SoftCOM) Conf, pages 1–6, 2011.

[21] Q. Lampin, D. Barthel, and F. Valois, "Efficient route redundancy in dag-based wireless sensor networks," in IEEE Wireless Commun. and Networking Conj., WCNC, 2010.

[22] Contiki: The Operating System for Connecting Next Billion Devices- the Internet of Things. Url: http://www.contiki-os.org/

[23] F. Osterlind, A. Dunkels, 1. Eriksson, N. Finne, and T. Voigt, "Cross- level sensor network simulation with COOJA," in Proc. of LCN, Nov. 2006, pp. 641-648.

[24] J. Tripathi, J. C. de Oliveira, J. P. Vasseur, " A Performance Evaluation Study of RPL: Routing Protocol for Low Power and Lossy Networks", IEEE 44th Annual Conference on Information Sciences and Systems (CISS), March 2010, pp. 1–6