Petrinet Model Based Validation of the LBRP for 6LoWPAN

Dr.M.Rehena Sulthana
Department of Computer Science
Mohamed Sathak College of arts and Science,
University of Madras, Chennai, India

Abstract

6LoWPAN is an architecture proposed by IETF working group that enables to carry IPv6 packets on top of the Wireless Personal Area Network (WPAN) standardized by the IEEE 802.15.4. In this paper, the working mechanism of the developed Location Based Routing Protocol for 6LoWPAN is modelled using simple Petri net and the performance of the protocol is validated using the reachability graph. From the computation of the reachability graph it can be seen that the token is reached at the destination as shown by the final marking. It is evident that the developed LBRP utilizing the link quality and the residual energy parameters through different nets reaches the ER. It is observed that the constructed Petri net is alive and no deadlocks are encountered.

Index Terms: - *6LoWPAN, LBRP, LQI, residual energy, Petri net*

I. INTRODUCTION

WSN consists of small nodes with sensing, computation and wireless communication capabilities deployed either inside the phenomenon or very close to it. The sensor nodes have special functions to sense and collect environmental information [16] like temperature, humidity, illumination etc.

In order to provide ubiquitous monitoring of any WSN applications, the node should be IP enabled. Since WSN is a network in which nodes are connected through low power wireless communications, direct adaptations of IP packet becomes cumbersome [1].6LoWPAN is an upcoming technology which morphs the sensed information over the Internet to provide remote access with the help of the adaptation layer. An efficient IPv6 communication over IEEE 802.15.4 links is provided by the adaptation layer [2][3].

Routing is a mechanism through which the information from any source node can be forwarded to a destination node. Due to energy constraint, routing in WSN performed in a multihop manner [4].Selection of best forwarding path will be the major criteria in designing a routing protocol based on 6LoWPAN WSN.

6LoWPAN allows for different network topologies where mutihop data transfer over intermediate nodes can be achieved to increase the covered area of the network and thereby remote data nodes can be reached [5].

In order to illustrate the effective changes occurring in the system with respect to different inputs to an analyst, a model is devised. Validation of the model is an important issue in modelling. The purpose of the validation technique is to assess the model with the known or predefined input parameters and comparisons of its output with the system output [8, 11].

Both the simulation and analytic models can be used to determine the realistic characteristic of the determined networks. There are several mathematical modeling techniques available such as markov chain model, stochastic model, probalistic model and Bayesian model which almost follow the time dependence nature and does not predict the change or growth in the network in the predefined fashion whereas Petri net model merges the mathematical concepts with a graphical depiction to predict the changing behaviour of system of interest.

Petri nets depict the networks with respect to states and transitions where transitions are triggered by events. The developed Location Based Routing Protocol (LBRP) is modelled using Petri net and validated using reachability graph [4].

The primary objective of this paper is to depict the modelling and analysis of LBRP using Petri net. Further a comprehensive survey on the modelling and analysis of different protocols using Petri net is presented.

The rest of the paper is organized as follows. Section II provides the work related to Petri net and validation of the Petri net model. Section III discusses the modelling of the developed LBRP in detail. This paper concludes in section IV broaching the results and discussions of the developed LBRP.

II. RELATED WORK

Petri net is an excellent mathematical model introduced by Dr.Carl Adam Petri [7]. The dynamic behavior of the system in a network is described effectively using it [1], [8], [9], [11], [12]. The theoretical aspect of Petri net allows precise modelling and analysis of system behavior, while the graphical representation enables visualization of the modelled system state changes [10]. This combination is the main reason for the great success of Petri net.

Petri nets are composed of two basic components called places (p) and transitions (t). In graphical representation places are drawn as circles, transitions as bars or boxes. The directed arcs are used to connect places to transitions and to connect transitions to places. The state of the system is modelled by denoting the places with tokens. A place can be marked with a finite number of tokens. The marking of Petri nets is obtained by associating tokens with places where tokens are represented by small dark dots in the places. In Petri nets these tokens are utilized to depict the dynamic behavior and successive activities of the system.

Transition in Petri net is triggered or made active if one of its input places holds atleast one token. The state or condition of the system is modelled by marking the places with tokens. A place can be checked with a limited number of tokens. Hence to verify the performance of a routing protocol and to analyse it PN model can be used. Several protocols have been modelled using the Petri net in the literature [12, 13, and 15].

Chaoyue Xiong et al.[12] have presented a modelling and simulation of routing protocol for MANET using CPN. Here a topology approximation (TA) is used to address the problem of mobility in MANETs and simulated the AODV routing protocol. The TA mechanism describes the aggregate nature of nodes where their long term average behavior is of interest. This TA mechanism is used to build a CPN model of a MANET with an AODV routing protocol.

Cong Yuan and Jonathan Billington [13] have presented a colored Petri net model of the dynamic MANET On demand routing protocol. A CPN model is used for the formal verification of the DYMO routing protocol.

Meera Bala Krishnan et.al [14] has presented a stochastic Petrinet based approach for the reliability analysis of the applications. They have presented a comparative reliability analysis of an application on a corporate B-ISDN network under various alternate routing protocols.

Congzhe zhang et.al [17] has devised a systematic methodology for modelling and analysis of ad hoc networks. The Stochastic Petri net based model is used to represent an adhoc network.

Dan Li et al [15] have presented a Petri net model, which will find the bottleneck of PIM-SM (protocol Independent Multicast- Sparse Mode) protocol. They used the Stochastic Petri net approach for the performance evaluation of PIM-SM.

The analysis and the workflow of the developed LBRP are done using the Simple Petri net model. This model is used as it clearly depicts the workflow of the data in each and every phase in an elaborate manner. The key objective is to test the workflow of the data in the LBRP.

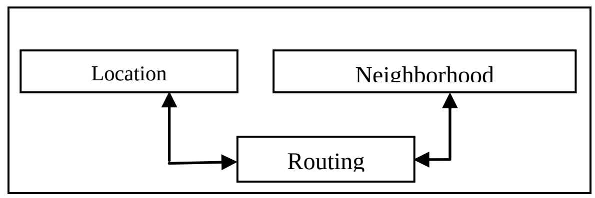

Fig 1. Architecture of the developed LBRP

The developed LBRP consists of three main modules and these modules coordinate with each other to perform the task of multi-hop routing for 6LoWPAN. The modules are location management, Neighborhood management and Routing management.

During the network initialization the ER or the sink node broadcasts its location information(x, y) along with its address. The LER and other RFD node uses the location information of the ER for further forwarding of data along with distance and the LQI as routing metric.

Neighbor discovery is done using the Neighbor discovery module. This module gets triggered, when the LER send the RREP in a unicast manner. The source sends the RREQ after sensing the event. RREP is given only by the nearby LERs and the neighbor table information is filled in the source node. Based on the maximum distance between LERs the best LER is chosen. Only the LER node does the RREP not the other nodes.

D_{max}= maximum distance (LER_1, LER2........LER_n)

Where 'N' represents the node.Every node maintains one routing table and neighbor table. Routing table consists of the ER address, ER location, Source address and Source location. The Neighbor table consists of the address of LER, its location and LQI. The neighbor table information is filled during the RREP process of LERs. The optimal forwarding LER node is selected based on the maximum weighted value in terms of LQI and distance (d) as expressed in the equation below.

$$LER_{best} = fn\ \{(d_{max})\ X\ (LQI_{best})\ X\ (E_{res})\} \qquad (1)$$

III. VALIDATION OF THE PROPOSED LBRP FOR 6LoWPAN USING SIMPLE PETRI NET MODEL

A. System Description of the LBRP

Basic interaction of the LBRP nodes is shown as the simple Petri net model in the Figure 2. The developed LBRP [4] system consists of 'm' number of places (nodes) and 'n' number of transitions. During the network initialization the ER or Sink node broadcasts its location information (x,y) along with its address. The LER (Local Edge Router) and other RFD (Reduced Function Device) nodes use the location information of the ER for further forwarding of data. After sensing the event, the source node broadcasts the RREQ (Route Request) to every single neighboring hub inside of its extent. After the reception of the RREQ, only the nearby LERs reply to those source nodes in a unicast manner and the neighbour table information gets stored into the source node. The neighbor table of the ER consists of the address of the LER, its location, LQI (Link Quality Indicator) and residual energy. The optimal forwarding LER node is selected based on the maximum weighted value in terms of maximum distance with the ER, LQI and residual energy as expressed in the equation (1) .

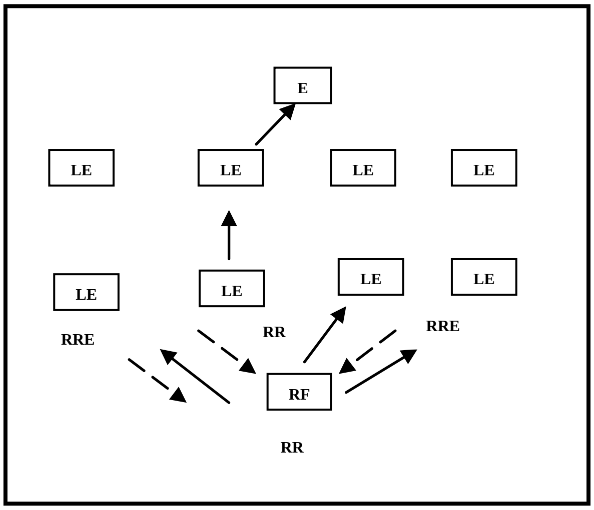

Fig.2.Interaction Model of the LBRP

Figure 3 represents the regular interaction sequence among the ER, LER and RFD nodes. Using ND (Neighbour Discovery) mechanism each node present in the network discovers its neighbours as shown in Figure 1. The neighbor discovery protocol classifies the nodes into two categories namely hosts and routers. Host nodes are basically the source node, while router nodes are the intermediate nodes that enable communication with the destination. Edge router is considered to be the destination node that interfaces with Internet to formulate 6LoWPAN.

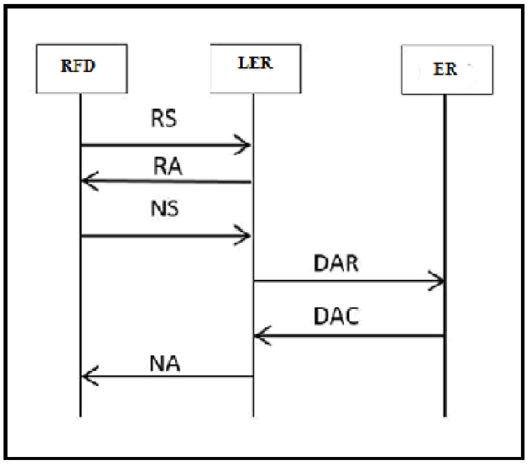

Fig. 3. LBRP system interaction diagram

The developed LBRP is modelled using Petri nets. Let nodes be modelled as places which are categorized into three types namely ER, LER and RFD. Each node involved in the data flow is represented by a place with an input transition showing the beginning of the activity and an output transition indicating the end of the activity. In order to concentrate on the dynamic nature of the modeled system in terms of its states and change of states, each place conceivably holds one or more tokens. Tokens are a primitive idea for Petri nets notwithstanding places and transitions. The vicinity or deficiency of token in a place indicates whether a condition connected with the place is true or false. If true, transition begins, if not, it will not begin. The transitions t1 till t13 allows the tokens (data packets) to move from one place to another till it reaches the destination (ER) with the help of links.

The packets used to estimate the routing protocol is depicted as weights which at the trigger of the events are moved from one place to another. During the movement of tokens the links are chosen with the maximum weighted value of three items such as maximum distance with ER and with the best LQI and residual energy.

B. System Modelling using Petri net:

Petri net (PN) is a particular kind of bipartite directed graph populated by three types of objects namely places, transitions, and directed arcs.

In its simplest form, a Petri net can be represented by a transition together with an input place and an output place. This elementary net may be used to represent various aspects of the modelled systems [9].

The developed LBRP is modelled using Petri nets. Let nodes be modelled as places which are categorized into three types namely ER, LER and RFD. Each node involved in the data flow is represented by a place with an input transition showing the beginning of the activity and an output transition indicating the end of the activity. In order to study the dynamic behavior of the modelled system in term of its states and change of states, each place potentially holds either none or a positive number of tokens. Tokens are primitive concepts for Petri nets in addition to places and transitions. The presence or absence of token (event) in a place (node) indicate whether a condition associated with the place is true (event sensed) or false (event not sensed). If true, transition begins, if not, it will not begin. The transitions t1 till t13 allows the tokens (data packets) to move from one place to another till it reaches the destination (ER) with the help of links.

The packets used to estimate the routing protocol is depicted as weights which at the trigger of the events are moved from one place to another. During the movement of tokens the links are chosen with the maximum weighted value of three items such as maximum distance with ER and with the best quality and with the best LQI and residual energy.

IV RESULTS AND DISCUSSIONS

The proposed PN model of the LBRP shows the data flow movement inside the 6LoWPAN network. Figure shows the initial state of the LBRP PN model. It consists of three nets called N1, N2 and N3.

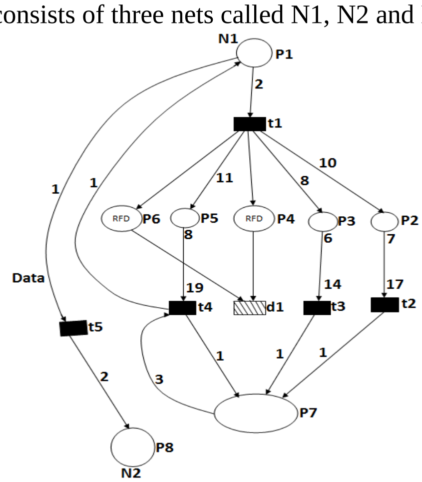

Fig. 3. Initial State of PN model

The whole operation of the framework (or) system can be isolated into three stages. The initial stage N1 as shown in Figure 3, where the transition t1 is invoked by the pushing of two tokens from the source P1. When t1 fires, the distance are added with the LQI and the residual energy in the P2, P3, P4, P5, P6 places. When t2 is enabled one token is pushed into the P7 state. At the same time P4 and P6 is sent to the 'stop' state as they are RFDs. Similarly when t3 and t4 is enabled, one token is pushed to the P7 state. As a result 3 tokens are present in the P7 state. Finally the best LER is chosen in the P7 state and one token is passed to the P1 state. Finally interaction between the source with the selected LER is done when t5 fires and two tokens are passed to the next net called N2 i.e. P8 state.

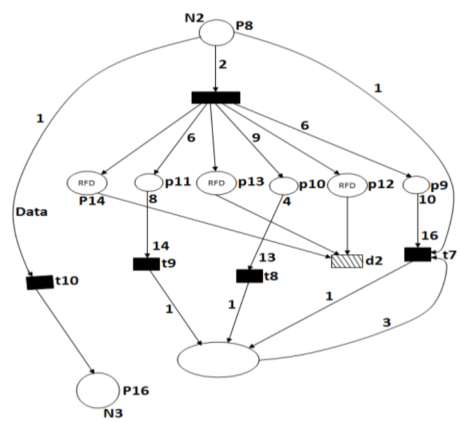

Fig. 4. Intermediate State of PN model

Similarly the same interaction happens in next stage N2 and N3. Finally data from N3 net is passed to the Edge Router (ER) as shown in the Figure 4 and Figure 5.

Figure 6 depicts the reachability graph of the Petri net model illustrating all possible sequences of activities, it holds 24 states, P1...........P24. The node P1 holds the initial marking N1. According to Figure 6, the properties of LBRP system are as follows.

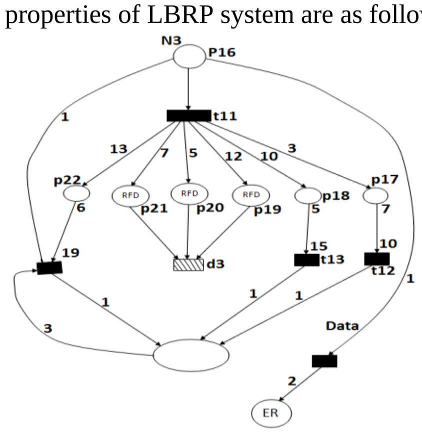

Fig.5. Final State of PN model

Reachability graph refers to the effort to get starting with one vertex then onto the next within a graph. A source vertex‘s’ can reach the destination vertex‘t’ if there exists a succession of contiguous vertices. The reachability graph, R= (N, E), for Petri net = (P,T,I,O). N= n_1, n_2...n_i, each n_i corresponds to a Petri net marking. $\mu_i = (\mu_{i1}, \mu_{i2}, \mu_{i3}..... \mu_{in})$.
E= {......., (n_k,n_r), ...} where there is a transition from p_{ik} to p_{ir} and a series of markings that causes that transition to be taken. Reachability graph for a safe conservative vertex Petri net with ‘n’ places and ‘k’ tokens can potentially have n^k nodes. Reachability graphs can be optimized to produce interesting results (eg. State transition model).

Petri net reachability graph analysis is used to check the characteristic of each reachable state. Finally with the benefit of reachability analysis there is not a need to analyse the whole system and it can be used to evaluate the subsystems. Also it can be used to evaluate high level design. Hence this reachability graph analysis is used to validate the developed LBRP. Here in this reachability graph it is evident that the token indicated as ‘2’ moving from the source ‘p1’ reaches the destination ‘ER’ after going through all the transitions from t1 till t15.

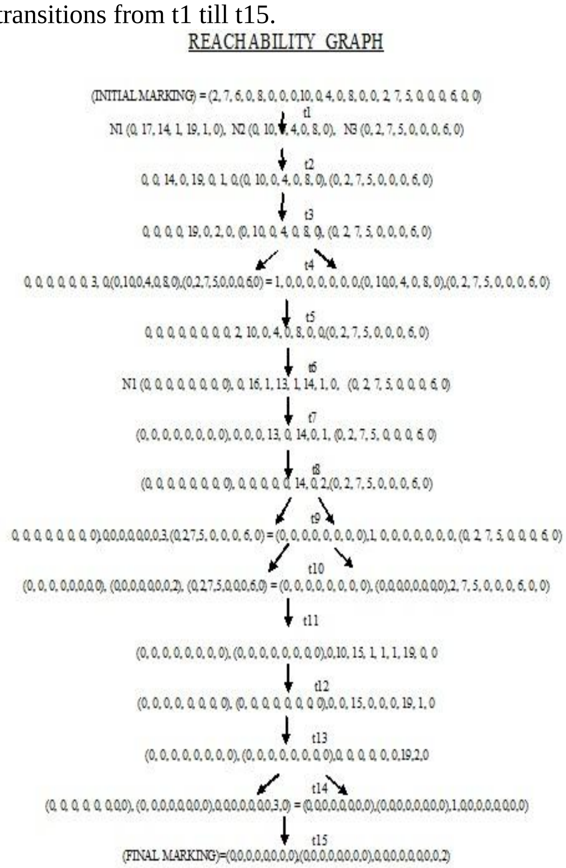

Fig. 6.Validation of PN Model through Reachability Graph

IV. CONCLUSION

This paper uses Petri nets to model the developed Location based routing protocol. The LBRP utilized in the system expands the LOAD [5][6] mechanism to bolster energy efficient transmission formats between the RFDs and LERs to reach ER. The feasibility of the system is confirmed through Petri net model analysis. The developed work has been done for Intra-PAN routing in 6LoWPAN. Further it can be extended to Extra-PAN routing. It can also be extended for mobile environment of the network. Also the Petri net validation analysis of the developed LBRP can be analyzed for fault tolerance of the node.

REFERENCES

[1] Zach Shelby, Carsten Bormann. (2009),"6LoWPAN: The Wireless Embedded Internet’, Wiley Publications", United Kingdom.
[2] Jonathan Hui, David Culler, E (2010). "IPv6 in Low-Power Wireless Networks", Proceedings of the IEEE, Volume 98, No.11, 1865-1878.
[3] Jamal N. Al-Karaki, Ahmed E. Kamal, “Routing Techniques in Wireless Sensor Networks: A Survey”, IEEE Wireless Communications, pp. 6-28, 2004.
[4] M.Rehena Sulthana, P.T.V Bhuvaneswari, N.Rama, "Enhanced Location Based Routing Protocol for 6LoWPAN", International Journal of Computer Networks & Communications (IJCNC) Vol.4, No.3, May 2012, pp.no. 93-108.
[5] Kim. K, Daniel Park, Montenegro and Kushalnagar, N, “6LoWPAN Ad hoc On-Demand Distance vector Routing (LOAD)”, IETF, draft-daniel-6lowpan-load-adhoc-routing-03.txt, pp.no.1-17, 2007.
[6] Perkins. C, Beding Royer. E, Das. S (2003), 'Ad hoc On-Demand Distance Vector (AODV)', IETF, RFC 3561,1-37.
[7] Vedran Kordic ,"Petri Net, Theory and Applications", I-Tech Education and Publishing, Vienna, Austria, 2008.
[8] Baumgarten, B. "Petri nets basics and applications", II edition, Berlin, Spektrum Akademischer Verlag, 1996.
[9] Reisig, W."Petri nets –An Introduction to Petri nets", EATCS monographs in Theoretical Computer Science, Springer-Verlag , 1985.
[10] Murata, T. " Petri nets: Properties, Analysis and Applications", Proceedings of the IEEE, Vol.77 (4), pp.541-580, 1989.
[11] Aalst,W.vader,Hee,K. Van."Workflow Management:Models,Methods and Systems. Massachusetts", MIT Press, USA, 2002.
[12] Chaoyue Xiong, Tadao Murata, Jeffery Tsai. "Modelling and Simulation of Routing Protocol for Mobile Ad hoc Networks Using Colored Petri Nets", Proceedings of the conference on Application and theory of petri nets: formal methods in software engineering and defence systems, Australian Computer Society, Volume 12, pp.145-153, 2002.
[13] Cong Yuan and Jonathan Billington. "A Coloured Petri Net Model of the Dynamic MANET On-demand Routing Protocol ", Proceedings Seventh Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools, Denmark, pp. 37-56, , 2006.
[14] Meera Bala krishnan, Kishor S. Trivedi. "Stochastic Petri Nets for the Reliability Analysis of Communication Network Applications with Alternate Routing ", Reliability Engineering and System Safety, Elsevier, pp. 243-259, 1996.

[15] Dan Li, Yong Cui, Ke Xu , Jian Ping Wu. " Improvement of multicast routing protocol using Petri nets", Proceedings of the 10th international conference on Rough Sets, Fuzzy Sets, Data Mining, and Granular Computing - Volume Part II, Springer-Verlag Berlin, Heidelberg, pp.634-643, 2005.
[16] Jennifer Yick, Biswanath mukherjee, Dipak Ghosal, "Wireless Sensor Networks, Elsevier –Computer Networks",pp.2292-2330, 2008.
[17] Congzhe Zhang, Mengchu Zhou. "A Stochastic Petri Net Approach to Modelling and Analysis of Ad hoc Network", IEEE, pp.152-156, 2003.