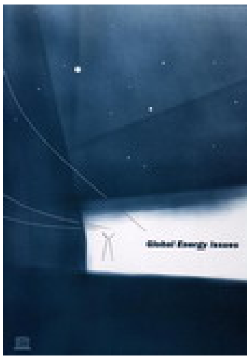


International Journal of Global Energy Issues

ISSN online: 1741-5128 - ISSN print: 0954-7118
https://www.inderscience.com/ijgei

Analysis and research of communication network system based on low power loss routing protocol

Wenming Cai, Xin Niu

DOI: 10.1504/IJGEI.2023.10055833

Article History:

Received:	30 December 2021
Last revised:	15 March 2022
Accepted:	27 September 2022
Published online:	03 December 2023

Analysis and research of communication network system based on low power loss routing protocol

Wenming Cai

Artificial Intelligence College,
Zhejiang Industry & Trade Vocational College,
Wenzhou 325003, Zhejiang, China
Email: cwm120085@163.com

Xin Niu*

College of Architectural Engineering,
Changzhou Vocational Institute of Engineering,
Changzhou 213164, Jiangsu, China
Email: 8000000326@czie.edu.cn
*Corresponding author

Abstract: In view of LLN communication network system has broad prospects for development. In this paper, the RPL routing protocol in the LLN communication network system is the main research content. Aiming at the deficiency of RPL routing protocol in high load communication network, a low power loss routing protocol based on load balancing LLN is proposed in this paper. This protocol can increase the connectivity and coverage of the communication network system, and can balance the data load of the network system effectively, improve the overall throughput of the communication network, further prolong the life cycle of the communication network system and ensure the normal communication work of the communication network system through the low power dissipation network routing protocol based on load balance LLN.

Keywords: LLNs; load balancing; RPL; low power consumption; lossy network; routing protocol.

Reference to this paper should be made as follows: Cai, W. and Niu, X. (2024) 'Analysis and research of communication network system based on low power loss routing protocol', *Int. J. Global Energy Issues*, Vol. 46, Nos. 1/2, pp.59–68.

Biographical notes: Wenming Cai received her master's degree in communication and information system from Xidian University in 2010. Currently she works in Artificial Intelligence College of Zhejiang Industry & Trade Vocational College. Her research interests include the internet of things, data communication, embedded system development and electronic circuits.

Xin Niu received his master's degree in computer application technology from Nanjing University of Science and Technology in 2007. He works in Changzhou Vocational Institute of Engineering. His main research directions are building intelligent technology, computer network technology, internet of things generic technology.

1 Introduction

With the development of new technology in the field of communication network system, the low-power lossless network technology has gradually attracted the attention of scholars and experts all over the world. Low power loss communication network system with green environment protection and energy saving has the characteristics of low power and limited data processing ability of communication nodes. Routing Protocol for LLNs (RPL), as a low power loss communication network routing protocol widely used in the world, deeply designs the network topology construction, communication route selection and data transmission optimisation mechanism of communication nodes in the network. The design focuses on the realisation of data interaction mechanism of communication nodes in the process of communication network system, and lacks specific parameter optimisation for the parent node selection of data nodes in the process of routing. The RPL protocol needs to be improved and perfected in the process of communication network application.

In the actual application of communication network system, the performance of communication network will show great difference because of many objective factors, such as routing algorithm, node type of equipment, etc. According to the characteristics of low power loss network, low power nodes and relatively long life cycle are undoubtedly the key bottlenecks to limit low power loss network system performance. The unbalanced load in the communication network will lead to the excessive load of some equipment nodes, which will lead to the premature depletion of the energy of the equipment nodes, thus greatly affecting the stability of the communication network. In communication networks, such as network routing protocol's own defects, different network application scenarios, system environment factors, randomness of device node distribution will lead to load imbalance. The content of supplementary answers, this part of the content, is added to the content of the red treatment. High bit error rate and low power consumption bring contradiction between reliability and energy saving to LLN.

Generally speaking, in order to improve the reliability, data redundancy and error recovery mechanism are usually increased in the process of data transmission, while in order to save energy, the data redundancy and the number of data transmission times need to be reduced. Considering the common application fields of LLN network, the two cannot make a simple trade-off. Low reliability rate of data transmission may cause business interruption, which may cause serious consequences in some application fields (such as military reconnaissance, real-time monitoring, medical care, etc.). On the other hand, high energy consumption may cause nodes and networks to fail in advance and make business completely interrupted. Therefore, it is of great significance to study the reliable transmission technology of LLN network which takes into account the energy saving demand.

The data in the LLN network can be divided into several types according to the characteristics of the information carried. Among them, the two most typical types are:

1 A large number of conventional data. This type of data often contains short messages such as temperature, humidity, blood pressure, short text, etc., and a large number of data, but each data is encapsulated in a shorter message length. This type of data has a higher requirement for reliability, but has a lower tolerance for latency.

2 Large volumes of real-time multimedia data, which require lower reliability but higher latency tolerance and higher network speed.

Communication network systems often operate on unstable types of communication media, which are inherent in Communication network systems and are often referred to as ‘Lossy’. Each device node of this kind of communication network system has the characteristics of low power consumption, limited computing capacity and low data storage resources. Therefore, communication network systems with these characteristics are called Low-power and Lossy Networks (LLNs). At present, LLNs are still in the process of being perfected, and the standards of LLNs protocols are being formulated. LLNs are in the initial stage of application and implementation. Due to the rapid development of communication technology, low equipment node cost, microprocessor and low power consumption of CPU technology, LLNs system has broad application prospects, gradually attracted more and more attention.

At present, communication network, industry, agriculture, home, construction, education, transportation, medical care and other fields are LLNs communication network system more extensive application scenarios. There are different data communication routing requirements in different industries, which brings different challenges to the deployment and performance of LLNs network. According to the characteristics of LLNs communication network system and broad application scenarios, the ROLL working group of IETF specially formulates the RPL protocol (Routing Protocol for Low-power and Lossy Networks), which is a distance vector communication routing network protocol. The RPL protocol constructs a purposeful Destination Oriented Directed Acyccgraph (DOG) based on the metric level and the target function, and then calculates the optimal route of data transmission according to the constraint conditions of each device node and the routing metric level of nodes.

The performance of network routing protocol affects the performance of communication network system to a great extent. RIP, OSPF, BGP, EIGRP and other routing protocols used in traditional Ethernet cannot be used in the low power communication network, which has strict requirement on energy consumption and resources. RPL, which is different from traditional Ethernet routing protocol, is optimised for low power consumption and limited resource of devices in communication network system. A lot of research work has been done on RPL communication network protocols by research institutes in various countries. In constructing DODAG, data transmission hop is used as routing metric, which can effectively improve the real-time performance of data transmission, but cannot guarantee the reliability of data transmission (Thubert, 2012). In the construction of DODAG, the expected data transmission times are used as the route metric of the system, which can effectively improve the reliability of data transmission, but cannot guarantee the real-time of data transmission (Gnawali and Levis, 2012). If the routing metrics designed in Thubert (2012) and Gnawali and Levis (2012) are used in the communication network system with high load, the load balancing of the communication network system will not be realised well.

2 Related work

In order to improve the load balancing ability of RPL routing protocol in high load scenario, this paper proposes a low power loss LLN routing protocol based on load balancing in high load scenario. The agreement mainly includes the following two aspects:

1 In order to avoid that the parent node of the alternative equipment with large amount of data transmission is selected as the optimal device parent in the communication network system based on low power loss network routing protocol, the process of selecting the device parent node is optimised by comprehensively considering the expected number of data transfers between the current device node and its parent node of the alternative equipment in the communication network system.

2 When the running equipment nodes are in network congestion, a kind of congestion notification message of communication network system is designed to timely announce the current congestion status of communication network system (Mayzaud et al., 2017).

Although packet loss due to device node data congestion in a communication network system is accidental, it does not adversely affect block data transmission, but only increases the time for retransmission and recovery of the sending rate. The slow start and congestion avoidance algorithm is very effective in controlling the data flow. However, TCP's approach to handling packet loss does not work well for interactive, loss-sensitive, and time-sensitive traffic.

Another problem related to device node data congestion is the impact of congestion on multiple data streams. When a device node begins to discard incoming packets, it generally does not distinguish between data flows. When multiple TCP streams result in packet loss, all streams have to reduce their own sending rate. Depending on the degree of device node congestion, multiple streams will gradually recover their own sending rates. This reduces the utilisation of the device nodes and associated links until all TCP data streams are restored to the rate at which they were sent before congestion. The device node has returned from a congested state to a low usage state.

The throughput problems caused by congestion due to retransmission and low link usage are the result of managing congestion only through the sender. To avoid a series of problems caused by packet loss due to router congestion, TCP/IP designers have created some standards for hosts and routers. These standards describe active queues taking place on an IP router.

The management algorithm (AQM) (RFC 2309) enables device nodes to monitor the status of forwarding queues to provide a mechanism for device nodes to report congestion to the sender, allowing the sender to slow down before the device node begins to lose packets. This reporting and host response mechanism is referred to as explicit congestion notification (ECN) (RFC 3168). When congestion occurs, the device nodes must slow down their sending rate. To avoid packet loss, the loss of sensitive packet flow will not be greatly affected by congestion.

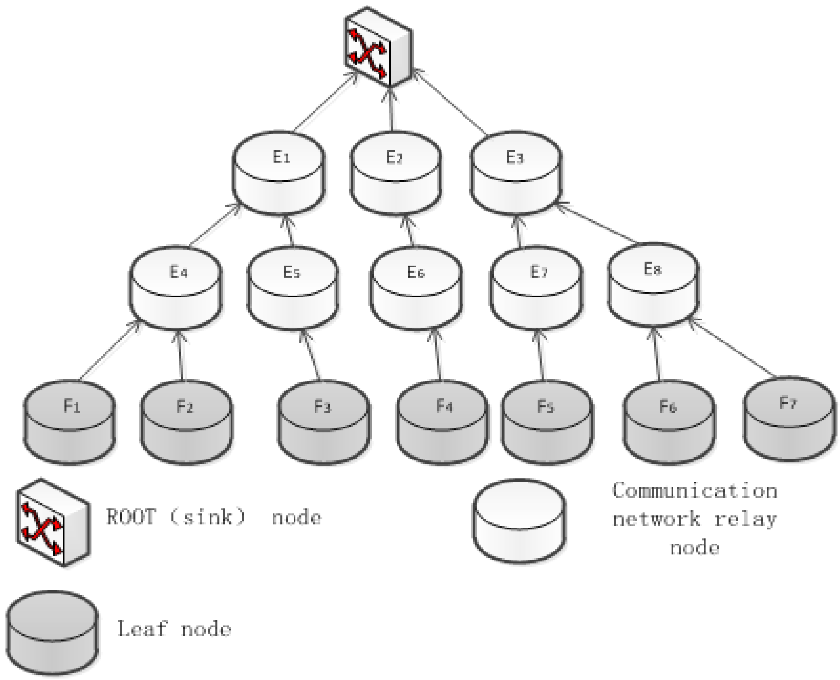
Through the two improved optimisation techniques, the control overhead of communication network system can be reduced and the average life of communication network system can be prolonged.

3 Proposed method

In the high load communication network scenario, the network topology model diagram based on load balancing LLN low-power lossy network routing protocol, as shown in Figure 1.

In this network model, the SINK node is designed as the sink node of the communication network, providing the sink function for all kinds of data traffic transmitted from the downstream device node to the upstream device node. E1-E8 is the relay node of the communication network, transmitting all kinds of data flow generated by all leaf nodes of the communication network, F1–F7 is the leaf node, generating all kinds of data flow, and transmitting all kinds of data flow to the upstream node.

Figure 1 Network model of LLN low power dissipation lossy network routing protocol based on load balancing in high load communication network scenario



In this communication network system, all device nodes have the same properties and properties except for the communication network sink node SINK. In the communication network system, all the equipment nodes work in static mode, so as to maximise the stability of the network system. In the communication network system, all device nodes have enough storage space to cache the routing table entries (Mayzaud et al., 2016). Each device node can not only send out data information, but also receive data information and do the corresponding processing.

3.1 Selection and optimisation of the optimal device parent node

In the process of topology construction of communication network system, when the communication device node selects the optimal device parent, it usually selects and confirms the optimal device parent according to the routing metrics of different network systems, and confirms the optimal device parent according to such information as the number of data transmission hops, the energy state of the device node, the expected data transmission times and the buffer occupancy rate of the device node. The number of hops in data transmission can effectively express the real-time status of data transmission, and the expected times of data transmission can reflect the reliability of data transmission.

In this paper, we propose a new low-power lossy LLN routing protocol based on load balancing, which combines the two routing metrics, data transmission hops and expected data transmission times, and considers the reliability and real-time of data transmission.

In a communication network system, when selecting the optimal device parent, not only the expected number of times of data transfer with the device parent in the current hop range, but also the number of hops between the device parent and the hop on the device parent in the data transfer process should be taken into account (Tsao et al., 2015). In order to balance the load of communication network system, it is necessary to reduce the hops of the devices and the probability of selecting the parent node as the optimal parent node.

Consider the device node *P*, which has two alternate device parent nodes *X* and *Y*. The flowchart for selecting the optimal device parent node is shown in Figure 2.

Optimal device parent node selection optimisation implementation process for device node *P* is given below:

Step 1: Alternate device parent nodes *X* and *Y* of device node *P* calculate their respective expected number of data transfers through equation (1), respectively. The expected number of data transmissions is the reciprocal of the quality of the data links between the nodes in the communication network system (Le et al., 2016), indicating the average number of times a device node needs to successfully transmit a packet to its parent:

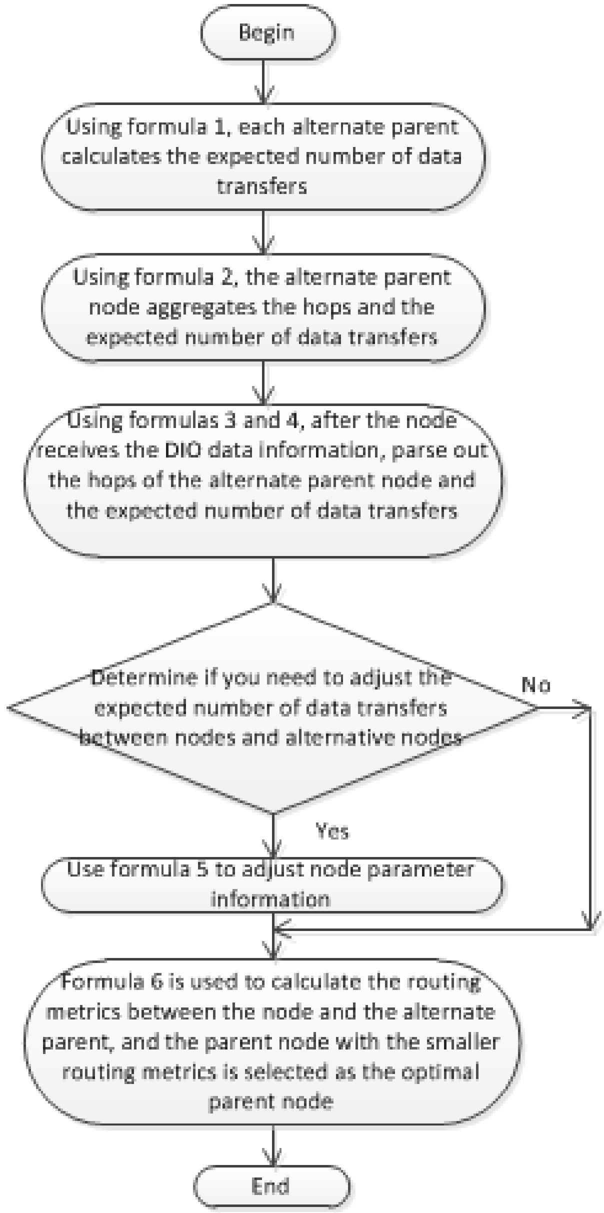
$$ETX_{U \to V_U} = \frac{1}{H(U, V_U)} \tag{1}$$

In equation (1), *ETX* represents the expected number of data transfers (Expected Transmission Count) and $H(U, V_U)$ represents the quality of the communication network link between the device node *U* and its parent node V_U.

Step 2: Nodes *X* and *Y* gather the expected data transmission times and data transmission hops respectively, transmit the aggregated data through the DIO control message of periodical broadcasting, and transmit the result of data information aggregation to the device node *P*. Expected data transfer times and data transfer hops are aggregated as shown in equation (2):

$$\begin{aligned} RANK(U) &= O \times Y_{rank} + (O-1) / ETX_{U \to V_U} \\ &= O(Z(U)+1) + (O-1) / ETX_{U \to V_U} \end{aligned} \tag{2}$$

Figure 2 Flowchart for selecting the optimal device parent node



In equation (2), Y_{rank} represents the previous network depth value of node Y, and Z (U) represents the number of hops that node U sends IP packets to the root node of the communication network system. O is the aggregation factor for data information. This value can be designed as an appropriate positive integer, such as 5 or 50. This article sets O to 40. Two functions of parameter O are:

1 Used for data aggregation between expected data transmission times and data transmission hops at the transmission end.

2 It is used for the receiving end to parse the expected data transmission times and data transmission hops.

Step 3: Once node *P* receives the DIO data control message broadcast by node *X* and *Y*, node *X* and *Y* can be parsed.

The number of hops and the expected number of data transfers. The expected number of times of data information transmission and the number of data transmission hops shall be resolved as shown in equations (3) and (4):

$$ETX_{U \to V_U} = \frac{O-1}{MOD\left(RANK\left(U\right), O\right)} \tag{3}$$

$$Z\left(U\right) = \left(\frac{RANK\left(U\right)}{O}\right) - 1 \tag{4}$$

In equation (3), MOD ( ) is a modulo logic operation; in equation (4), { } is a descending integer operation.

Step 4: Node *P* resolves the expected number of data transfers between node *X* and *Y* and determines whether its values need to be matched against node *X*.

The expected number of data transfers between *Y* is adjusted as shown in equation (5):

$$ETX_{P \to U} = MAX\left(ETX_{P \to U}, ETX_{U \to V_U}\right) \tag{5}$$

Step 5: Node *P* calculates the routing metrics between nodes *X* and *Y* respectively, and then reduces the routing metrics to a smaller number.

A node of is its best parent. The calculation formula for the routing measure, as shown in equation (6):

$$R\left(t, U\right) = Z\left(U\right) + 1 + ETX_{t \to U} \tag{6}$$

$R(t, U)$ represents routing measures, and $Z(U)$ represents the number of hops that a node *U* sends a packet to the root node of a communication network system. *O* is the aggregation factor, and the value of *O* can be some suitable positive integer.

3.2 Network congestion status notification policy based on low power dissipation lossy network routing protocol in high load communication network scenario

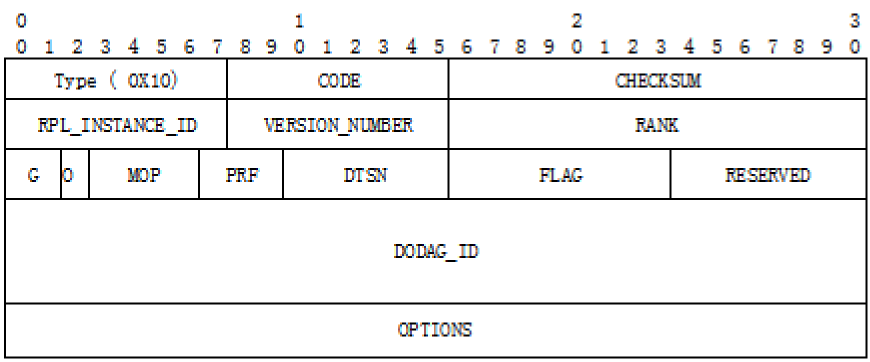
In the scenario of high load communication network, the communication network congestion is easy to occur. In the LLN, if a communication network is detected, and if a node in the network is in a congestion state, the congestion state of the network node should be transmitted to its next child node to process the network congestion. For example: change the transmission path of data information, or adjust the transmission rate of data information (Perrey, 2013).

In a communication network system using RPL protocol, when a node is in a network congestion state, the DIO control message of periodic broadcast will be used to carry the network congestion state of the node, and the network congestion state will be announced to its children. In the RPL protocol, the Trickle timer manages and controls the interval between messages sent by the DIO. When no node in a communication network stops working or a new node joins the system, the interval of sending DIO messages increases gradually, which results in that the system cannot tell its children and neighbours the information of the node in the network congestion state in time.

In summary, in order to minimise the overhead of resource consumption in communication network systems, the network congestion will occur in real time.

In the scenario of high load communication network, a kind of network congestion notification control message is introduced in the low power lossy network routing protocol based on load balancing LLN (Wallgren et al., 2013). The frame format of this communication network congestion notification control message is basically the same as the frame format of the DIO data control message (the type field can be set to 0x10), which is shown in Figure 3.

Figure 3 Frame format of congestion notification control message in communication network



Nodes in the state of network congestion only need to use multicast to their children to transmit the message of network congestion notification control and complete the notification of network congestion (Airehrour et al., 2017). A node is judged to be congested if its state satisfies the following two conditions:

1 The data cache space occupancy rate of the node exceeds 65% of the default network congestion value of the network system;

2 At the current moment, the number of node acceptance rate divided by contract issuance rate is greater than 1.

When a node satisfies the above two conditions, it is judged to be in the network congestion state. Multicast is used to transmit the congestion notification control message to its child nodes to complete the network congestion notification. The child nodes will then either reselect the parent node or perform a data shunt operation (Raza et al., 2013). If the node does not meet the above two conditions, it is determined that it is not in a congestion state.

4 Conclusion

In the scenario of high load communication network, the low power loss routing protocol based on load balancing LLN can effectively improve the performance of communication network. The agreement mainly includes the following contents:

1. Optimal Parent Selection and Optimisation: In the networking process of communication network system, the two routing metrics are combined: node data transmission hop and expected data transmission times.
2. Network congestion notification strategy: when network congestion occurs, multicast shall be adopted to transmit network congestion notification control messages and complete notification of network congestion status (Mayzaud et al., 2014).

With the increasing demand for various network resources, the scale of LLN network is also expanding in various industries, and the number of all kinds of equipment nodes will continue to increase.

References

Airehrour, D., Gutierrez, J. and Ray, S.K. (2017) 'A testbed implementation of a trust-aware RPL routing protocol', *Proceedings of the 2017 27th International Telecommunication Networks and Applications Conference* (*ITNAC*), IEEE, Melbourne, Australia, pp.1–6.

Gnawali, O. and Levis, P. (2012) *RFC 6719. The minimum rank with hysteresis objective function*, Standards Track, IETF.

Le, A., Loo, J., Chai, K. and Aiash, M. (2016) 'A specification-based ids for detecting attacks on RPL-based network topology', *Information*, Vol. 7, No. 2, p.25.

Mayzaud, A., Badonnel, R. and Chrisment, I. (2016) 'Detecting version number attacks in RPL-based networks using a distributed monitoring architecture', *Proceedings of the 2016 12th International Conference on Network and Service Management* (*CNSM*).

Mayzaud, A., Badonnel, R. and Chrisment, I. (2017) 'A distributed monitoring strategy for detecting version number attacks in RPL-based networks', *IEEE Transactions on Network and Service Management*, Vol. 14, No. 2, pp.472–486.

Mayzaud, A., Sehgal, A., Badonnel, R., Chrisment, I. and Schonwalder, J. (2014) 'A study of RPL dodag version attacks', *Proceedings of the IFIP International Conference on Autonomous Infrastructure, Management and Security*, Springer, Brno, Czech Republic.

Perrey, H. (2013) *On Secure Routing in Low-Power and Lossy Networks: 8e Case of RPL*, Master of Science, Department of Computer Science, Hamburg University of Applied Sciences, Hamburg, Germany.

Raza, S., Wallgren, L. and Voigt, T. (2013) 'SVELTE: real-time intrusion detection in the internet of things', *Adhoc Networks*, Vol. 11, No. 8, pp.2661–2674.

Thubert, P. (2012) *RFC 6552. Objective function zero for the routing protocol for low-power and lossy networks*, Standards Track, IETF.

Tsao, T., Alexander, R., Dohler, M., Daza, V., Lozano, A. and Richardson, M. (2015) *A security threat analysis for the routing protocol for low-power and lossy networks (RPLs), request for comments*. Available online at: https://rfc-editor.org/rfc/rfc7416.txt

Wallgren, L., Raza, S. and Voigt, T. (2013) 'Routing attacks and countermeasures in the RPL-based internet of things', *International Journal of Distributed Sensor Networks*, Vol. 9, No. 8.