ISSN: 2664-9640

A Cross-layer Optimization Algorithm for COAP Based on MAC Layer

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Abstract

Since a large number of mobile terminals join the ubiquitous power Internet of Things network in the form of self-organization or multi-hop, the network should realize the three functions of data acquisition, processing and interaction of the ubiquitous power Internet of Things.However, due to the wide distribution, large number of terminal nodes and limited resources, it is a great challenge for both grid load and terminal nodes to carry out data collection, processing and information exchange under the condition of random communication and random change of channel conditions in this network.Therefore, it is particularly important to improve the accuracy, real-time performance and reliability of the data.In this paper, we design a cross-layer Optimization Algorithm for COAP Based on MAC layer (MCP-COAP) is proposed to solve the problem that the network topology is not perfect and the channel utilization rate is low due to the lack of combination between PLC power line carrier communication at the bottom of ubiquitous power Internet of Things and the upper-layer protocol.By establishing pipe connection between application layer and MAC layer, information sharing and accurate information transmission are realized, so as to achieve the purpose of optimizing network performance.

Keywords

Ubiquitous in the Internet of Things; CoAP; Cross-Layer Optimization; MAC protocol.

1. Introduction

2019 national grid co.LTD, for the first time put forward the construction of "two net three type" strategic target of world-class energy Internet [1], its core is the construction of flood in the power of things in order to realize electric power business comprehensive perception [2], efficient processing, convenient application, integrated application of big data, cloud computing, emerging communication technologies such as artificial intelligence, realize the integration of power system equipment and communications technology. At present, the development of power system business is characterized by the explosive growth of information collection business, the development of control business end, and wide coverage [3].Due to the large number and wide range of ubiquitous power Internet of Things nodes, with the access of more and more resource-constrained nodes, the data transmission efficiency of inter-node application layer is affected, thus the ubiquitous interconnection and effective transmission of power information flow cannot be realized.

In order to improve The communication efficiency of The application layer of devices in The Internet of Things, The Internet Engineering Task Force (IETF) proposed The RFC7252 standard protocol specification in 2014.This paper designs a reasonable general Application layer communication Protocol based on Representational State Transfer (REST) architecture, that is, Contensed Application Protocol (COAP)[4]. This Protocol is similar to HTTP Protocol

ISSN: 2664-9640

and is often used for communication between nodes in low-power and resource-constrained network, with the main goal of meeting special requirements in resource-constrained environment of nodes such as the Internet of Things.

Ubiqual Electric IoT uses a traditional layered protocol stack, which shields each layer of the network from each other, so it is impossible to guarantee that the combination of each layer operating independently can achieve optimal network performance. For example, after the power user switches the channel, the upper layer cannot adapt to the dynamic change of the bottom layer quickly, and the COAP protocol of the application layer still uses the original parameters, which will cause the low channel utilization rate or network congestion.

The original intention of the design of Ubiubiquitous Power IoT is to realize the efficient utilization of power business information flow, which highlights the importance and necessity of cross-layer optimization concept in Ubiubiquitous Power IoT. The ubiquitous cross-layer optimization in the electric power Internet of Things does not completely abandon the layered design of the traditional network. In the cross-layer optimization of COAP protocol, it does not mean that existing protocol standards are no longer needed, nor does it simply integrate the mechanism specifications of each layer. The idea of cross-layer optimization is to optimize the original COAP protocol through the sharing and interaction of key feature information between layers, so as to optimize the performance of the whole network.

Literature [5] proposed a COAP lightweight cross-layer optimization to establish a secure communication channel in the Internet of Things environment. Through cross-layer optimization of Transport Layer and application Layer, Datagram Transport Layer Security (DTLS) encryption mechanism is used to encrypt data in application Layer. Through the combination of DTLS encryption algorithm and COAP protocol, the secure session derived from the application layer is applied to the transport layer for encryption exchange, which ensures the security of the application layer transmission.

In literature [6] COAP group communication was introduced to reduce the network entry time and the number of interactive messages, and a context-aware enhanced COAP protocol (ECTX-COAP) was proposed. However, ECTX-COAP protocol did not use the idea of cross-layer optimization when entering the network, failed to fully combine the characteristics of MAC layer, and only achieved local optimization rather than global optimization.

Therefore, this paper proposes a COAP cross-layer optimization algorithm based on MAC layer (MCP-COAP). MCP-COAP algorithm realizes the maximum utilization of power business information resources by cross-layer optimization of MAC layer to node application layer in the terminal node network.

2. COAP protocol and Problem description

2.1. CoAP Protocol

The design of COAP protocol is to meet the application layer communication requirements of resource-constrained network and Internet of Things. The schematic diagram of its protocol stack is shown in Figure 1. In order to meet the lightweight requirements of COAP protocol, UDP is used as the transport layer protocol and data is interacted through request/response model.

Logically, the COAP protocol adopts a two-layer structure. The Messages Layer is used for data interaction and congestion control between nodes. The Requests/Responses Layer performs HTTP-like resource manipulation methods, including GET to retrieve resources, POST to create resources, PUT to update resources, and DELETE to DELETE resources.

There are four Message types defined in the COAP protocol, namely CON (Confirmable Message) which needs to be confirmed, NON (non-confirmable Message) which doesn't need to be

ISSN: 2664-9640

confirmed, ACK (Ackkonwledge Message) reply Message and RST (Reset Message) Reset Message. Through these four kinds of messages, the COAP protocol realizes both the unreliable transmission and the lightweight reliable transmission in the Internet of Things scenario.

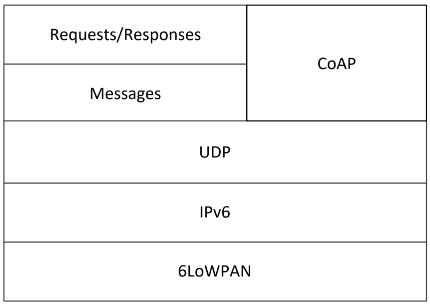

Figure1: CoAP Protocol stack

2.2. Problem Description

Through the research on COAP protocol of ubiquitous power Internet of Things, the following problems are found:

The characteristics of the underlying links of the ubiquitous power Internet of Things are quite different, and the dynamic variation is strong, which is easy to cause the disordering between different packet streams. On the one hand, packet disordering is easy to cause the network congestion and affect the sending rate.On the other hand, application layer data packets can not interact in time, affecting the operation of power business.The dynamic change of link is mainly reflected in the transmission bandwidth, round-trip delay, packet loss rate and other dynamic changes with the change of link environment.

Ubibious power Internet of Things is an applied Internet of Things that takes power business data as the center and is used to perceive and acquire various information within the scope of the power grid. Therefore, the key to correct and reliable data collection and transmission is the Ubibious power Internet of Things.However, the characteristics of massive network nodes and limited resources require its application layer protocol to be more efficient and concise, so the transport layer protocol of COAP uses the unreliable UDP transport protocol.But this also leads to a decrease in network reliability.

At present, the ubiquitous electric Internet of Things mainly uses power lines for communication, and the data link layer protocol used is IEEE1901 protocol. Its frame format is shown in Figure 2. The main network medium is power lines, and the terminals are connected together through power lines to form the ubiquitous electric Internet of Things.

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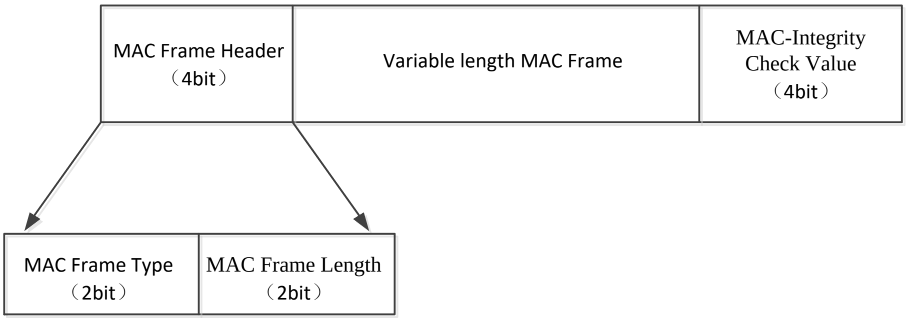

Figure 2: IEEE 1901 MAC frame format.

IEEE1901 Carrier Sense Multiple Access with Conflict Avoidance (CSMA/CA) is a MAC layer Access protocol that, in order to reduce transmission conflicts between nodes and further improve network throughput, listens the channel before data transmission to determine the idle or busy state of the channel, and then decides whether to transmit data.Its algorithm is defined as:

Back Process Counter (BPC) : Indicates the number of stages to retreat; Back Counter (BC) : Indicates a random retreat time.In {0,..., Cwi-1} is a random value, where Cwi-represents the competition window value of retreat stage I; Delay Counter (DC) : Used to evaluate the current channel busyness. The values of CWI and delay counter of the competing window corresponding to I and priority at different retreat stages are shown in Figure 3.

退避阶段i	CWi	DCi
0	8	0
1	16	1
2	32	3
⩾3	64	15

Figure 3: Values of CW and DC at different retreat stages.

3. MCP-CoAP protocol

3.1. COAP Congestion Control Algorithm Based on MAC Competition Window(MCW-CoAP)

Using interactive information competition in MAC layer control frame window the cw values to reflect the current network congestion and channel access between nodes is the competition, the algorithm using the start node according to the MAC layer is the competition of the next-hop link for CSMA/CA access channel, and channel access contention window the cw values embedded in the MAC interaction information control frame, and through the control of the situation of the frame relay link.

The specific implementation of the algorithm is as follows: the current value of cw of MAC layer of the network neutron node is fed back to the COAP sender through cross-layer transmission through the data packet received by the receiver. At the application layer, the COAP sender node periodically obtains the cw value of the competing window of the current link, calculates a cw value that can represent the current link congestion control according to the set of cw values of the child nodes along the way, and adjusts the RTO of COAP dynamically and adaptively by combining the historical cw value with the cross-layer optimization method. The dynamic RTO is used to adjust the transmission quantity of COAP packets in the network and realize the load balance of the network.

Because many generic in power iot node number and the link is not the same channel conditions, the pan in the multi-hop network of electric power iot, CoAP message transmission elements too much child node transmission and eventually arrived at the receiving end, therefore the MAC layer is of an arbitrary nodes along the CoAP connection network congestion will affect the entire network. Therefore, after COAP sends and receives the cw value set of each node along the way carried by the packet packet, the maximum value in the cw set is calculated as the cw value of the congestion state of the MAC layer of the whole network connection sent by COAP, namely:

$$cw = \max\{cw_{1,} cw_2, ..., cw_{n-1}, cw_n\} \tag{1.1}$$

In the formula, CWi serves as a data confirmation packet sent from COAP to the cw value of the competitive retreat window of the MAC layer passing through the ith node along the COAP receiver's route.

In order to conveniently represent the degree of network congestion, we converted the cw value to cw_value. Since in IEEE1901, the default value of cw was [8, 16, 32, 64], formula (1.2) was used to transform the cw value to [0, 1, 2, 3, 4], and the corresponding relationship was:

$$cw\_value = \log_2(cw) - 4 \tag{1.2}$$

In order to record the historical dynamic change of CW value, we introduce cw_change to record the historical dynamic change of the competitive retreat window, and adopt Formula (1.3) to carry out iterative calculation:

$$cw\_change = \begin{cases} 0.5 * cw\_change + 0.5 * cw\_value & cw\_value > 0 \\ \partial * cw\_change & cw\_value = 0 \end{cases} \tag{1.3}$$

Where, cw_value is the estimated value of the congestion condition of MAC layer of the whole link after COAP receives the competitive retreat window value of nodes along the data stream. The initial value of Cw_change is 0, where ∂ is the default constant with a range of为0<∂<1.

After calculating the cw_change value, the COAP layer judges the MAC channel competition and conflict situation of the whole link according to cw_change, and adjusts the COAP timeout retransmission RTO value according to Equation (1.4).

$$RTO = \begin{cases} \text{floor}(RTO/2) & cw\_change \le \theta \\ RTO + 2 & cw\_change > \theta \end{cases} \tag{1.4}$$

In the formula, the function floor (RTO/2) takes the largest integer not exceeding RTO/2, where θ is the constant set. The initial value of RTO in this formula is the default value of 2s in COAP protocol, In Formula (1.4), when cw_change exceeds constant θ, it means that the current link is experiencing serious MAC channel competition. In this case, the RTO value in COAP protocol should be increased to limit the number of COAP packets entering the network.When cw_change is less than constant θ, it indicates that the current data flow link is in a relatively stable state. In order to make full use of channel resources, the RTO value in the COAP protocol should be appropriately reduced to make more COAP packets enter the network and increase the throughput of the network. The complete flow chart of MCW-COAP is shown in Figure 4:

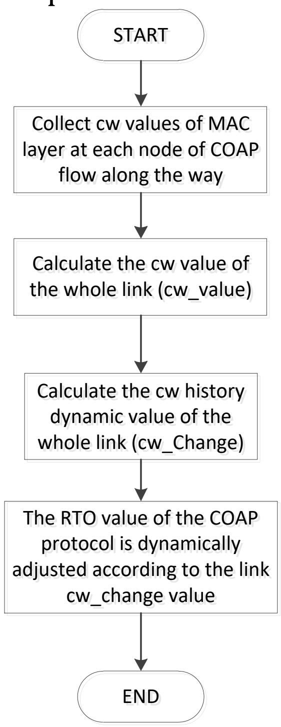

Figure 4: Flow chart of MCW-COAP algorithm

3.2. COAP algorithm based on MAC node access perception

In the pan in the power of things, CoAP agreement calls for each terminal node must periodically broadcast network registration, and in the net, the end-to-end packet transmission is broken, was supposed to arrive at this stage the ACK packet source node is access to the late arrival of registration behavior, lead to the application layer CoAP protocol for network congestion occurs, start timeout retransmission packets, causing the network channel utilization rate reduced.

In order to avoid the above unnecessary timeout retransmission phenomenon, it is necessary to effectively distinguish the data transmission network congestion and the timeout retransmission caused by network registration. So we introduce the cross layer optimization idea, proposed to the net registration behavior on the MAC layer, save CoAP control overhead and redundant information, and at the MAC layer and layer CoAP, realize effective interaction and sharing of information between CoAP need access to MAC layer net start/end time, channel switching began to end time, and the parameters of the current channel and so on.

Firstly, we define the format of the MAC layer access control frame, and add the source and destination node addresses as well as the start and end time of the node access to the MAC layer access control frame, as shown in Figure 5, where the source and destination address are both the source and destination node addresses in the COAP packet of the application layer.

The bytes	2	4	4	4	4
	Frame type	Destination address	Source address	Network entry start time	End of network entry time

Figure 4: MAC access control frame format

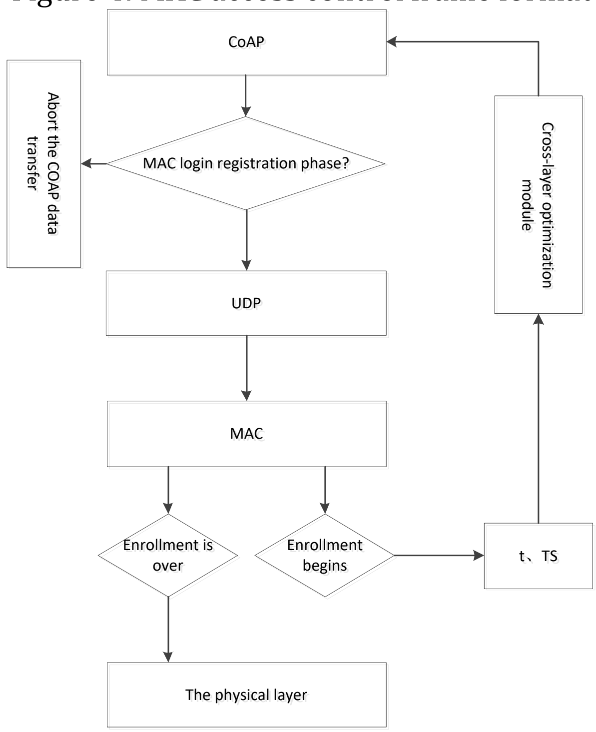

Figure 6: Schematic diagram of cross-layer optimization of COAP and MAC layers

CoAP layer and MAC layer of cross-layer collaboration diagram as shown in figure 6, set at time t MAC layer to access registration, the MAC layer to time t and the net time Ts by cross layer module share transfer to CoAP, CoAP layer within [t ,t + Ts] not for packet transmission, if CoAP message in the time period[t ,t + Ts] happen in overtime retransmission, as is the net registration message delay, is not recognized as CoAP retransmission, to reset the CoAP RTO.When the network registration phase is over, the COAP packet ACK delayed by the network entry message can be transmitted normally without causing network congestion.In the registration stage of MAC layer, in order to avoid overflowing the data cache of nodes, COAP layer does not transfer data packets to the bottom layer.To be registered after the end of the network, and then resume the transmission of data packets.

ISSN: 2664-9640

In CoAP，MCP-CoAP mechanism proposed in this paper using a MAC and CoAP cross-layer congestion control mechanism of writing and MAC node net perception mechanism, competition will RTO estimate and MAC layer retreat algorithm together, the greatest degree of accuracy to the RTO value of network, and use the MAC layer parameters save CoAP control overhead, significantly improved in the pan in power iot scenarios CoAP performance.

4. Emulation Proof

4.1. Simulation Paramenter Setting

In this chapter, OPNET 14.5 simulation tool on Window operating system is used to simulate MCP-COAP protocol, ECTX-COAP protocol and COAP original protocol, compare and analyze their network performance, and verify the superiority of MCP-COAP. The specific parameters are set as shown in Table 1 below.

Main Paramenter Setting

Simulation Parameter	Value of Number
Simulation running time(s)	100
Simulation scene size(km2)	10×10
Data number	81
Transmission distance(m)	[100,200,300,400,500]
Packet generation interval (s)	10
Carrier frequency (GHz)	340
Link bandwidth (Kbs/s)	50
Data frame(bits)	64
Send the cache (Mbps)	10

During the whole simulation process, the traffic between nodes remains unchanged. According to the different distances between nodes, five different scenarios are set, corresponding to two contrast protocols respectively in each scenario. Simulation scenarios are set according to the above parameters. The simulation experiments under four random SEED values were repeated for 20 times, and it was found that the simulation results corresponding to different random SEED numbers were similar. The 95% confidence interval of the overall mean value was taken as the final simulation data for analysis.

4.2. Analysis of Simulation Result

Network throughput: As shown in Figure 7, MCP-CoAP has a higher network throughput compared with ECTX-CoAP and CoAP protocol, mainly for two reasons.

The main reasons are as follows: Increase with the distance between the nodes, the uncertainty of network link gradually strengthen, MCP - CoAP algorithm through its "based on MAC and CoAP cross-layer congestion control mechanism of collaboration" and "MAC node net perception mechanism" will CoAP packet transmission and the combination of MAC layer, through perceived link from adaptive adjustment CoAP, reduce network congestion, save CoAP net registration phase, reduces the control overhead, reduce the channel load and reduce packet buffer time, The idea of cross-layer optimization is introduced on the original COAP protocol to improve the network throughput of COAP protocol in the ubiquitous power Internet of Things scenario.

A new adaptive half-beam forming mechanism in LDLO-M

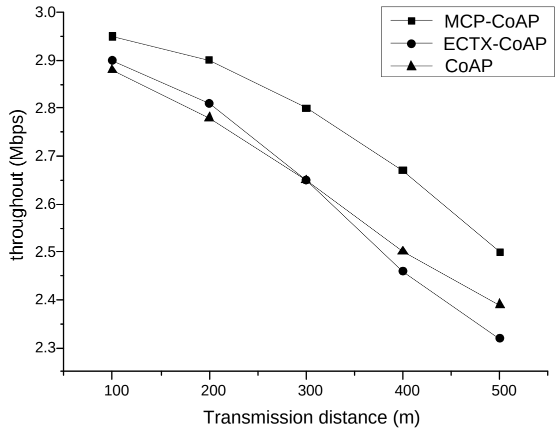

Figure 7: Network throughout

Average Delay: As shown in fig. 8, compared with Terahertz ECTX-CoAP and CoAP, MCP-CoAP protocol reduces the average delay under the condition of traffic saturation. The main reasons are as follows: with the increase of the distance between nodes, the network link becomes complex, the transmission distance of packets through the power line increases, and the delay begins to increase.MCP - CoAP algorithm through the "MAC node net perception mechanism", put a CoAP registered in MAC layer, reduced the CoAP control costs, reduce the channel load, reduced the CoAP packet transmission delay, reduce the total network latency, and MCP - CoAP algorithm CoAP congestion control mechanism was optimized by the MAC layer, reduce the probability of error CoAP packet retransmission, reduces the total time delay.

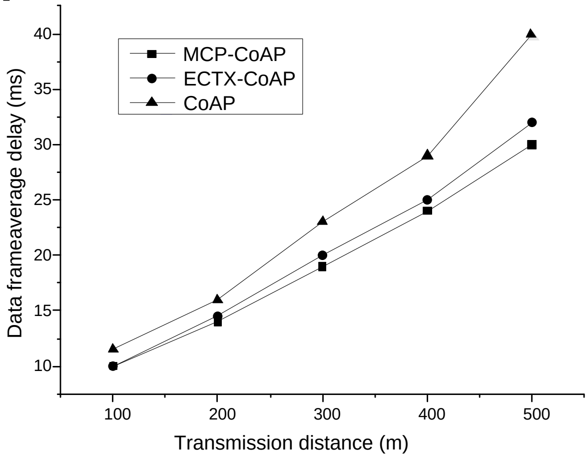

Figure 8: Data frame average delay

Success Rate of Packet Transmission: As shown in fig. 9, Simulation results show that the node distance is small packet transmission rate is close to 96%, but as the node increases the distance between the distance, three algorithms of packet transmission rate were significantly decreased, but the MCP-CoAP algorithm has a higher success rate of packet transmission, compared with the ECTX-CoAP algorithm increased 16.84% on average, than the original CoAP protocol average of 21.39%.

The main reasons are as follows: with the increase of the distance between nodes, the network link is unstable, which increases the problem of invisible terminals in the network, and the communication distance becomes longer, which also increases the probability of network link terminals.ECTX-CoAP introduced CoAP group communication, reduced the number of node access time and message interaction but only up to the local optimal CoAP application layer, failed to achieve the global optimal, and MCP-CoAP algorithm because of its cross layer optimization with MAC layer, through the "based on MAC and CoAP cross-layer congestion control algorithm of collaboration" will CSMA/CA of MAC layer combined with CoAP congestion control, realized the pan in the power of the Internet of things the global optimal balance.

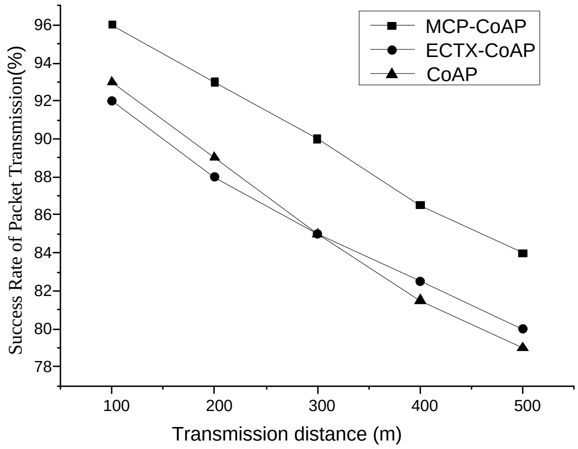

Figure 9: Success Rate of Packet Transmission

5. Conclusion

In this chapter, the IEEE1901 protocol is introduced firstly, and then the traditional hierarchical network of ubiquitous power Internet of Things is deeply analyzed, such as the great influence of the bottom link, the excessive control overhead of the application layer and the overall suboptimal network. Then, A cross-layer optimization algorithm for COAP based on MAC layer (MCP-COAP) is proposed based on these problems. Then, two new mechanisms, the congestion control algorithm based on cross-layer cooperation between MAC and COAP and MAC node access perception, adopted by MCP-COAP are described in detail. Through the collection of simulation statistics analysis after the three agreements, verify the MCP - CoAP in pan under the power iot scenarios can be combination of MAC layer and the CoAP application layer, effectively solved the problem of stability and the overhead of the network of the underlying link, save money and reduce the data transmission delay, improve the network throughput and the packet transmission rate.

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