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An Asymmetric Transport Protocol for Internet of Things

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Abstract

Energy consumption by wireless sensor nodes has always been a key issue for the Internet of Things (IoT)due to the characteristics of constrained resources in the sensor nodes. As Compared to the traditional network nodes, it is easy to examine those traditional network nodes and sensor nodes that co-exist in IoT are extremely asymmetric in terms of network bandwidth, memory space and processing power. On the other hand, most current protocols that we use are designed for traditional networks without considering the asymmetric relationship between the different types of nodes. In the paper, we propose an asymmetric transport protocol that respects the asymmetric nature of the communicating nodes through reducing energy consumption or computation of the resource-constrained nodes so that the service life of the resource-constrained nodes can be prolonged. We will also verify the goal of the protocol design to show that the protocol design can decrease the energy consumption and the latency of data packets transmission as compared to the transmission control protocol (TCP).

*Keywords:*Internet of Things (IoT); communication protocols; resource-constrained nodes; asymmetry; load transfer.

1. Introduction

Rapid development of communications technologies has started to blend the model of man-machine-things of Internet of Things [1, 2] into our lives. The technologies not only make communications between human beings more convenient, but also make communications between humans and things as well as things to things possible. In such networks, a serious issue exists for not only the sensor nodes but also the mobile phone nodes, that is, the increased power consumption. Therefore, designing protocols that would reduce energy consumption of low power wireless nodes for IoT networks has become our vision for future development.

Current IoT networks generally consists three types of nodes, i.e., sensor nodes, routing nodes and mufti-protocol gateways. In addition, edge routers, base stations and wireless routers are used to link small devices together to form a real global network. Due to protocol conversion, however, mufti-protocol gateways become the performance

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bottleneck. Meanwhile, the direct interconnection between different types of nodes can be realized by giving abundant IP addresses in IPv6, and removing the need for mufti-protocol gateways[3]. Till now, transport protocols mostly rely on TCP [4,5] which provides connection oriented, reliable data transmission services to ensure the end-to-end reliability of data transmission. To make it more convenient, more and more mobile devices are connected to the network through the cellular networks[6]. The battery capacity of the mobile devices is usually limited and could not balance with the network energy consumption.However, in the IoT networks, the sensor nodes are highly resource-constrained and extremely asymmetric as compared to normal PC and server nodes. In addition to the differences in terms of capacity of the bandwidth, memory space and processing power[7].

In this paper, we propose an asymmetric network transport protocol, in which the powerful end nodes take a higher level of communication and computing loads while the low-ability end nodes handle lower communication and computing work. The goal of the proposed asymmetric network transport protocol is to reduce energy consumption in the resource-constrained nodes to make them work longer, which is extremely important for applications where resource-constrained nodes are based entirely on the batteries.The remainder of the paper is organized as follows. Section II comments some related work. Section III depicts the protocol design and Section IV provides the results of some experiment we conducted to evaluate the proposed protocol to verify its effectiveness. Finally, we summarize the paper in Section V .

2. Related work

It is considered unrealistic to apply the IP protocol to wireless communication networks although it is not entirely impossible. Current wireless networks use a dedicated protocol because the IP protocol has a strict requirement on memory and bandwidth and it is difficult to change its operating parameters to adapt to the micro controllers and low power wireless connections. 6LoWPAN [8-10] has been proposed for low power operations that make it suitable for the requirements. The lower layer of 6LowPAN uses the PHY layer and the MAC layer from the IEEE802.15.4 while the network layer continues to adopt the IPv6 protocol. 6LoWPAN protocol is proposed to reduce the insurance consumption, bandwidth consumption, demand and energy consumption. Moreover, due to the features of the low speed wireless domain network, the adaptation layer introduced in 6LoWPAN will undoubtedly introduce delays or stagnation in the transmission function and security for the high capacity nodes.

Currently, there is some research on the realization of web service technology for IoT in resource-constrained nodes for resource saving [11]. In the research on network protocols, it is usual to reduce the burden on resource-constrained nodes in existing protocols (IPv6, IPsec, SSL, TLS, HTTP, etc.) [12-14]. In order to reduce the IP network layer payload, Granjal proposed to compress AH and ESP security heads to be between 81 and 102 bytes [15] to deal with the constraints of the nodes. However, this approach also reduces the length of the secret key while lowering energy consumption, which is likely to weaken security as well as other functions. Song proposed a streamlined IPv6 protocol that is ideal for a wireless sensor network by cutting on the existing IPv6 [16] in which the neighbor table in the link layer address information, the destination address of the buffer and the duplicate address detection are delete. Such approach of compressing or reducing the communication protocol often leads to the reduction of the security or the functionality of data communication. However, the development of mobile devices don't favor the approach of simply reducing the consumption of resources and the compression of communication protocols.

3. The proposed protocol

We mainly bases on asymmetric communication ideas and low energy consumption to design the four phases that include initialization, congestion avoidance, data re-transmission and data recovery. Initialization phase takes place before other phase, during this phase, the receivers establish a parameter to acknowledge the message to both communications and the senders set congestion window(cwnd) to 1 for the detection of network status. During the congestion avoidance phase, the congestion window will implement linear growth to prevent rapid growth of the sending packets from the sender. Lastly, the sender enters into data re-transmission phase and data recovery phase when acknowledge packet has W_{cong}. The internet node uses the way to increase the cache or computation to reduce the loads of resource-constrained node. The efficiency of network communication and the lower energy consumption of resource-constrained nodes are obviously improved through the redesign of the acknowledged packet and the asymmetric design. We have listed and explained the notations of the protocol parameters in Table 1.

Table 1.Parameter symbols

Notation	Explanation
RTT	a connection’s round-trip time
Sack	The sum of packet numbers in a round of transmission. It is a variable
cwnd	congestion window
ssthresh	slow start threshold
N	The number of sending packets in a round
n	The number of lost packets after a round
Wcong	the loss packet sequence number

3.1. Initialization phase of the protocol

Firstly, we build an acknowledge packet that includes a parameter S_{ack} to represent the sum of packet numbers in a round of transmission as shown in Figure 1(a).During the transmission of packets, it is likely to have the congestion problem in the network if the sender has injected a large number of packets into the network immediately due to the lack of information in the network. Therefore, the initialization phase will increase the size of the congestion window gradually, playing a role in the detection of network status.

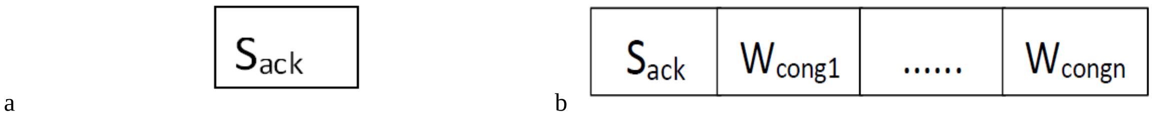


Fig.1.(a) Acknowledge packet for the initialization phase.(b)Acknowledge packet for packet re-transmission scheme

(1) When a new connection is established, the cwnd is initialized to 1. This means that the size of one packet that can also be determined by the other party or a default value which is commonly 535k or 512k, will be converted to smaller packets by 6LoWPAN in WSN.

(2) When the resource-constrained node at the receiving end receives the data packet from the sender, it will send S_{ack} to the sender as the confirmation of the correct packet. Then, the sending end receives the correct value of the S_{ack} i.e.1 from the receiving end, it will compute RTT and update cwnd=cwnd*2. Then, the resource-constrained node will receive the correct value of the S_{ack}=1 from the receiving end, it will update cwnd=cwnd*2. Meanwhile, at the end of each round, the receiver will reset S_{ack}=0.

(3) At the sender side, when the S_{ack} from the receiver and the sum of packet numbers are the same, the sender will continue to double the size of cwnd that is (2) repeatedly. Otherwise, the sender will recognize the error and enters into the data recovery phase.

(4) When cwnd≥ssthresh, the network enters the congestion avoidance phase.

3.2. Congestion avoidance phase of the protocol

Network congestion is the decrease in the performance of a network transmission and the limitation in the network resources because of too many packets transmitted into the network. It is a state of continuous overload of the network, when user’s demand for network resources exceeds the inherent processing and capacity. In order to prevent the network congestion caused by the rapid growth of the congestion window, we set a ssthresh which is generally set to 65535 bytes to realize a slower start.

(1) When the congestion avoidance starts, the ssthresh is set to half of the current cwnd, i.e.,ssthresh=cwnd/2.

(2) If cwnd⩾ssthresh, the sender will carry out the congestion avoidance algorithm and set cwnd=cwnd+1, i.e., the cwnd implement linear growth.
(3) If cwnd<ssthresh, the sender will execute the initialization algorithm.

3.3. Data re-transmission phase of the protocol

In the process of data transmission, the resource-constrained nodes have the imperfections of limited hardware resources, less bandwidth and communication links are vulnerable to environmental factors, so the packets may loss and can affect the data integrity.

A. Data re-transmission phase of the protocol

During transferring the data between the resource-constrained node and internet node, we can easily see that the internet node is stronger than the resource-constrained node in terms of the hardware resources or computing power. The data re-transmission will undoubtedly bring great energy consumption for the resource-constrained node, so we add a cache in the internet node to reduce a large amount of packets re-transmitted from the resource-constrained node and add the W_{cong} parameter to record the loss packet sequence number.
(1) When the number of the packets received are different from the expected receiving, we successively set W_{cong} equal to the sequence number of the packet not received and the packets received would be pushed into the cache of internet nodes.
(2) If there are n(n≦N) lost packets after a round, the receiver will return the acknowledge packet that includes Sack as well as n values of W_{cong} and store N-n received packets in the cache as shown in Figure 1(b).
(3) If the acknowledge packet has W_{cong}, the resource-constrained node will immediately resend n lost packets and enter into the fourth stage of data recovery.

B. Resource-constrained node as the receiver

Since packet loss and packets out of order may lead to receiving the unexpected packets, we repeatedly send the parameters of lost packet numbers to the sender until we receive the expected packets. However, we will immediately send the acknowledge packet to the sender when W_{cong} have the same three values, because of the probability of packet loss greatly increased. If the packets received are out of sequence, the problem will be resolved when W_{cong} have one or two of the same value. Therefore, it is necessary to re-transmit the lost packets rather than timeout.
(1) when the receiver receives the unexpected packets, it will set W_{cong} to the lost packet number and Sack does not increase again, until it receives the expected packet number. If the resource-constrained node receives three of the same value of the W_{cong}, the acknowledge packet will immediately be sent.
(2) The sender receives three of the same values of W_{cong}, it is identified to be the packet loss, then get into the fast recovery phase.

3.4. Data recovery phase of the protocol

The design of data recovery, especially for the large congestion window, can greatly improve the throughout capacity of communication in the whole network and can reduce the energy consumption of the resource-constrained nodes when the congestion level is moderate.
(1) After the re-transmission of packets, the sender sets cwnd=ssthresh+3.
(2) When the sender receives an acknowledge packet,and has W_{cong}, it sets cwnd=cwnd+3. If the window size is logical, the sender will transmit the packets.
(3) when the acknowledgment packet have not send W_{cong} to the sender, set cwnd= ssthresh and get into phase of congestion avoidance.
(4) When the re-transmission timeout, ssthresh=cwnd/2, cwnd=1, then enters the slow start phase.

4. Experiment

4.1. The simulation model

We used NS-2 network simulation environment[17] to perform evaluation in which we ran two network transport protocols, the traditional TCP protocol and the proposed asymmetric ATP protocol, to let packet transmitted between the server and a energy-constrained node. Moreover, the traditional TCP is compared to ASP. For our simulation, a 1000m×1000m area is considered, where 50 nodes are randomly distributed. All nodes have the same transmission range of 250 meters. The simulation time is considered to be 50 seconds. The simulated traffic is Constant Bit Rate (CBR). The initial energy dedicated in the nodes, is 0.25J. The simulations are repeated several times and the average results are reported.

4.2. Comparison of energy consumption and Latency

From [18], it can be known that when the size of the packet is s bits, energy consumption for transmission and reception of the packet in the wireless sensor node are:

$$E_{transmit}=(\alpha dn+\beta)*s \quad (1)$$

$$E_{receive}=\beta *s \quad (2)$$

The d represents the distance, alpha, beta, and n are expressed as state parameters. In the ideal case, n=2, alpha =100pJ/bit/m2, beta=50nJ/bit. Therefore, energy consumption of the sending and receiving increase with the growth of large packets and is linear with the increase to the packet transmission when the distance is certain.

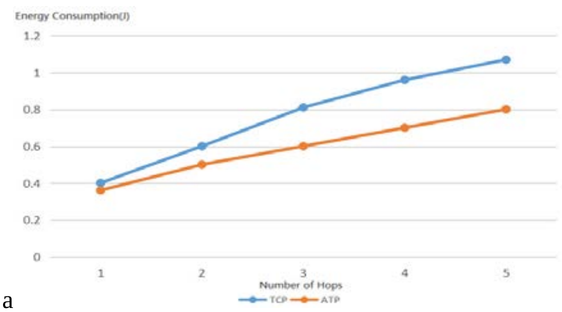
The energy consumption has not just only the transmit and receipt energy consumption, also the computation energy consumption that the size is relative with CPU power and time. Therefore, energy consumption for calculation of the packet transmission in the wireless sensor node are:

$$E_{cpu}=P_{cpu}*T_{cal}$$

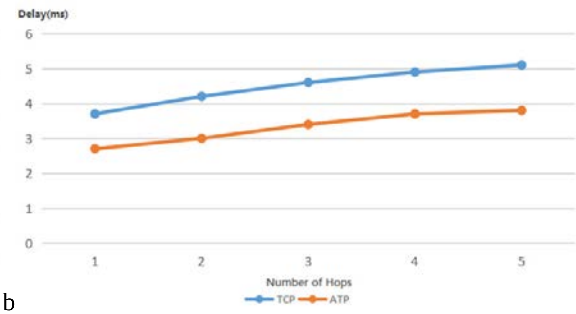
(3)

In summary, the formula for the energy consumption for the nodes of IoT:

$$E_{sum}=(\alpha dn+\beta)*s+\beta *s+P_{cpu}*T_{cal} \quad (4)$$



a



b

Fig 2.(a). Comparing the energy consumption.(b)Comparing the end to end delay.

We can see from the above analysis that the most energy consumption of sensor nodes is the sending and receiving, so we greatly change the algorithm to reduce the energy consumption of sensor nodes through reducing the transmit and receipt of packets. The asymmetric protocol aims to reduce the transmitted packets with increasing a bit addition operation in the four phases. Therefore the asymmetric protocol greatly reduces the energy consumption of the resource-constrained node. Figure 2(a) shows a comparison between ATP and TCP from the energy consumption viewpoint.

Figure 2(b) shows a comparison between ATP and TCP from the end-to-end delay viewpoint. Evidently, our proposed method provides a much less end-to-end delay, as compared with TCP. In fact, the RTO computation in the sensor nodes, and asymmetric data re-transmission reduces the burden of the sensor nodes and improves performance, thus reducing the latency of interaction.

5. Conclusion

In this paper, we presented an asymmetric transport layer protocol to suit the characteristics of asymmetry in IoT and tried to reduce the energy consumption of the resource-constrained node. Since the transmission and reception of packets are the main cause of energy consumption in the resource-constrained node, the protocol was designed by reducing the number of packets sent and received by the resource-constrained node while increasing some computation to realize the goal of lowering the energy consumption. Meanwhile, the computing loads of resource-constrained node was transferred to the internet node.We described the details of the protocol and performed some experiment to evaluate its effectiveness and to compare it to the traditional TCP protocol. From experiment and analysis, we can see that energy consumption and latency of the resource-constrained node can be reduced to about 20% and 26% on the average, which would help to improve the performance of the resource-constrained nodes

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