A Reliable Multicast Transport Protocol for Device Management in Space-ground Integrated Network

Mengfan Lv
State Key Laboratory of Information Security, Institute of Information Engineering, CAS, Beijing, China
Chinese Academy of Sciences
School of Cyber Security, University of Chinese Academy of Sciences, Beijing, China
lvmengfan@iie.ac.cn

Fenghua Li
State Key Laboratory of Information Security, Institute of Information Engineering, CAS, Beijing, China
Chinese Academy of Sciences
School of Cyber Security, University of Chinese Academy of Sciences, Beijing, China
lifenghua@iie.ac.cn

Lingcui Zhang*
State Key Laboratory of Information Security, Institute of Information Engineering, CAS, Beijing, China
Chinese Academy of Sciences
School of Cyber Security, University of Chinese Academy of Sciences, Beijing, China
zhanglingcui@iie.ac.cn
*Corresponding Author

Kui Geng
State Key Laboratory of Information Security, Institute of Information Engineering, CAS, Beijing, China
gengkui@iie.ac.cn

Kun He
State Key Laboratory of Information Security, Institute of Information Engineering, CAS, Beijing, China
Chinese Academy of Sciences
School of Cyber Security, University of Chinese Academy of Sciences, Beijing, China
hekun@iie.ac.cn

ABSTRACT

In the space-ground integrated network, management centers usually need to reliably send the same management information to different devices group. Considering the characteristics of satellite network in broadcast and limited resources, multicast protocol is more suitable for the device management than unicast protocol. However, the existing reliable multicast transport protocols tend to maintain a stable structure during the full lifecycle, which sharply reduces the efficiency and is not suitable for device management in satellite network. In this paper, we design a reliable multicast transport protocol for device management, which contains 2 key ideas: 1) In the aspect of acknowledgement aggregation, we design a rapidly tree-organized scheme for a temporary structure in each transmission, to reduce the time cost in dynamic multicast group forming. 2) In the aspect of local error recovery, we present an evaluation scheme in the quality of communication, to choose a less-energy-cost way between local multicast and local broadcast to relay. Effective performances of the schemes are showed in the experiments.

CCS Concepts

• **Networks → Network protocols → Network protocol design**

ICMSSP '18, April 28–30, 2018, Shenzhen, China

ACM ISBN 978-1-4503-6457-7/18/04...$15.00
https://doi.org/10.1145/3220162.3220173

Keywords

Reliable multicast; local error recovery; alternative scheme in relay; rapidly tree-organized scheme

1. INTRODUCTION

As a mean to manage the devices, the control information plays a crucial role. Therefore, it must be sent reliably. To deal with the same situation happened in various devices, the management message sent to different receivers keeps accord. Multicast provides a more efficient way to transmit device management messages than unicast. Moreover, multicast through satellite network large the global coverage and reduce the hops between sender and receivers. While satellite networks have the characteristics of high bit-error rate and limited uploads bandwidth, which limits the quality of reliable transmission. A reliable multicast protocol can be improved from feedback and retransmission to suit the satellite network.

The control message of devices is short but important. Moreover, every message of management accords to a specific threat, such as the information aiming at the Android system's bugs is only passed to the users of the Android. These characteristics distinguish control message from data message, e.g. video stream in [1]. Thus, the management message has the following additional problems. First, the control message is sent to different users from time to time, and the multicast structures changes frequently. Second, compared to the data message, which ups to MBs, and even GBs, the control message is much shorter. Third, the time spends in restructuring counts more than that spends in data transporting in the total time.

A classic solution in multicast for satellite is to organize a logical hierarchical tree in local error recovery, e.g. [2-4]. The aim of these protocols is to maintain a stable structure. Via the tree structure, messages retransmit to all nodes, including the dynamic ones for error recovery. While the device management messages may only needed to be passed to some of the nodes, maintaining a stable structure for all nodes over the time is quite inefficient. Hence, the stable structure loses it superiority, under the condition of destinations changing all the time, which is exactly the situation the device management protocol works for.

In this paper, we present a reliable multicast transport protocol for device management, to fix the problems met in the transmission. For the sake of the characteristics of the satellite network, acknowledgement aggregation and local error recovery are necessary for the protocol. In the protocol, we provide a rapidly forming prototyping structure for the multicast group in each message-spreading period, which can be used in both local error recovery and acknowledgement aggregation. In local error recovery, we provide an alternative scheme, choosing from the tree structure and broadcast, to retransmit the message. Due to the congestion control is provided by the protocols in transport layer, e.g. [5], and we work on the application layer, so it is not considered in this paper.

Compared with existing protocols, our contributions are the followings.

- **Fast-multicast tree building method.** We propose a method to cut the time used in tree structuring, which could fit the frequently changed destinations in device management, and evenly save the time used in transmission.
- **Autonomous retransmission alternative scheme.** We propose a scheme to optimize the tree multicast, in properly choosing a way to retransmit messages between the multicast and broadcast. The scheme bases on the communication quality during this transmission, and aims to reduce the overall energy consumption in a group.

This paper is organized as follows. Section II reviews the related work of multicast protocols. The multicast protocol of device management is presented in Section III. Results of experiment are given in Section IV. Conclusions are presented in Section V.

2. RELATED WORK

In [2], a logical hierarchical tree is created for local error recovery and acknowledgment aggregations to avoid message repeat and acknowledgement implosion in the low bandwidth link. In [3], a negative ACK (NACK) scheme is used for feedbacks of the incorrectly received content, and a packet level forward error correction (FEC) is used for local error recovery. The proxy takes the responsibility for the feedback and local FEC in the group. These protocols give good solutions in multicast for satellite. While their work cost a long time in waiting group numbers' acknowledgement and local error recovery before the proxy responding to the sender, which makes the message transmission inefficiently. And the stable structure they hold is not suitable for the device management.

In [6-8], a method of network coding is presented to improve the recovery efficiency in multicast retransmission. Network coding is to mix different incorrectly delivered information together before retransmission. It is a valid way to relay messages in reducing the packet numbers in the link. While under the condition of receivers changing often, the scheme could not work in its best situation.

In [9], a method of reliability guaranteed publish/subscribe service is presented to deal with large-scale multicast. The service works as a layered multicast, which could adjust autonomously and dynamically with the requirement of destination without generating overwhelming. In [10], the applicability of FEC is added in the structure for the reliability. But the destination of the service stays in a stable state, which does not change with the situation as that happens in the device management.

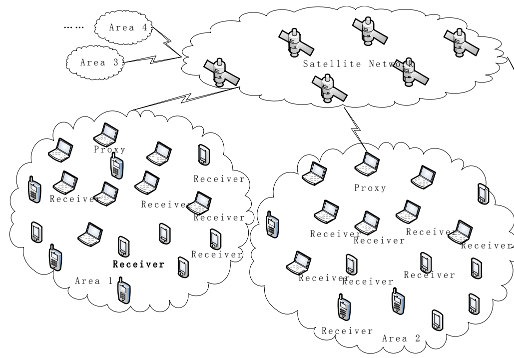

Figure 1. Satellite multicast scenario.

3. THE MULTICAST PROTOCOL

3.1 Structure

In this paper, we consider the multicast based on the scheme shown in [2] and [3]. The scenario is shown in Fig. 1. The sender holds all the receivers' knowledge about places, energies, network conditions, and so on. The receivers are in a huge number, dispersed in the planet. All of them could communicate to and from satellite. Some receivers may have terrestrial connection among them. Not all receivers necessarily need to be connected by terrestrial networks, but those who are in a certain scope and connect together by terrestrial network set into a group. Before sending the message, a packet level Forward Error Correction (FEC) with error correcting capability of t bits in the d-length is added.

The multicast protocol can be divided into two phases. In the first one, a sender connects with receivers via satellite link, which we called geo-satellite phase. In the second one, receivers organize to error-recovery and feedback among a group, which we called terrestrial phase.

3.2 The Geo-satellite Phase

The aim in this phase is to transfer control message from the sender to the receivers. Instead of getting all the nodes a reliable transport protocol, sender just promises only one node to hold the complete and correct message. The special node is named as proxy. Sender chooses the proxy among the group by the standard of comprehensive ability, which can be measure as follows:

$$\mathrm{F} = \mathrm{k}_1 * \mathrm{E} + \mathrm{k}_2 * \mathrm{B} + \mathrm{k}_3 * \mathrm{D} + \frac{\mathrm{k}_4}{\mathrm{M}} \tag{1}$$

Where F is comprehensive ability, E is energy, B is link bandwidth, D is node degree, M is node mobility, and k1 to k4 is adjusted coefficient, which can be adjusted according to actual situation. The knowledge of receivers mentioned above is known by sender before making the control message.

Before a reliable unicast sent to the proxy, the management centers send a broadcast via satellite to the area. All nodes in the area could hear the message, but the message may be wrong, due to high bit-error rate of satellite link. All the nodes could tell itself from destination field in the message head. If the node gets itself not in the filed, it drops off the packet. Otherwise the nodes keep the message ID and data for next phase. In some rare situations, mistakes may occur in the destination filed. Thus, nodes may improperly drop or keep the message. For the one wrongly drops, it could hold the message again in next phase. For the one wrongly keep, it could drop off the message by timeout scheme.

In the end of this phase, the proxy would hold the full and correct message, while the others may have the same copy.

3.3 The Terrestrial Phase

The aim in this phase is to set all receivers in a group get message completely and correctly. The phase can also be divided into two parts. One part works on local error recovery, the other works on acknowledgement aggregation. In local error recovery, the proxy retransmits the correct data to the needed nodes. After receiving the correct message, in acknowledge aggregation, normal nodes in the group feedback to the proxy, and the proxy feedbacks to the sender, which means the end of the transmission.

The multicast tree structure is suitable for the feedback transport for all the nodes need to transmit data to proxy. However, in the error recovery, only a part of the nodes need the duplicate from the proxy. And the number is affected by the quality of satellite communication. Therefore, we propose a scheme to evaluate the quality of communication, and choose a less-energy-cost way between local multicast and local broadcast.

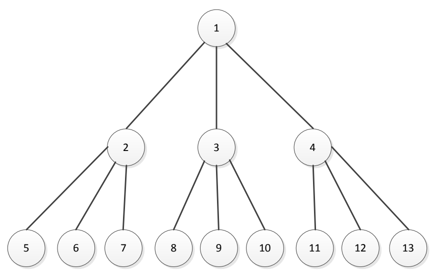

Figure 2. Multicast tree in K=3 scenario.

3.3.1 The Fast-multicast Tree Building Method

The tree is organized quickly by the clue of the destination filed in the packet, which can be seen as hierarchy traversal sequence of a tree with out-degree K. The number of K is adopted by sender, in considering the number and the distribution of nodes in a group. The destination filed keeps all nodes in a group in the order of the comprehensive ability, which counted in (1). In more details, a node knows its order, i. By the way, it can count the order of its parent, which is the top integral of (i-1)/K. It can also count the orders of its children, which are in range of (i*K-1, (i+1)*(K)-2).

From the field, a node gets the knowledge of its parent node and children nodes, where it sends the feedback to and gets the feedback from. For every node in the filed holds the clue, a logical multicast tree arises.

A typical multicast tree's building process is illustrated in Fig. 2. The 13 nodes are connected as the destination field's order. The root of the tree is the first node in the field. It has three children which are the second, the third and the fourth node in the field, as the K's value. The nodes in the tree have most 3 children, least none child, which called leaves. The leaves can grow in the lowest layer or the right part of the second lowest layer. A node turns to a leaf, because its children's number is beyond the total number in the field. In the feedback, the No.2 node receives feedback from three children nodes, No.5, No.6 and No.7. The node organizes the message and transmits to the No.1 nodes, which is the proxy.

3.3.2 The Autonomous Retransmission Alternative Scheme

The autonomous retransmission alternative scheme is used to choose a local error recovery way between multicast and broadcast. The local multicast tree bases on the tree built as the way mentioned in 3.3.1, and the broadcast can be seen as the variety of network coding.

We give the following assumption. In a group, the number of all nodes is N+1. The number of the nodes that fails to get the correct message is n. The energy cost in broadcast retransmission on the proxy is E_t. The energy cost in the retransmission between the two nodes is E_m. The energy cost in retransmission comparison on each node is E_c.

The energy cost in comparison in the broadcast is N*E_c. The energy cost in comparison via the multicast tree is n*E_c. The energy cost in retransmission via the multicast tree is 2*n*E_m.

When the sum of the energy that broadcast to all nodes is less than that in only retransmitted via the multicast tree, the relay in broadcast would be better for the group. It can be seen as follows:

$$\mathrm{N} * \mathrm{E_c} + \mathrm{E_t} < \mathrm{n} * \mathrm{E_c} + 2 * \mathrm{n} * \mathrm{E_m} \quad (2)$$

The equation (2) can be simplified by regarding the energy of broadcast, single retransmission and comparison as the same. Then it updates as follows:

$$\mathrm{n} > \frac{\mathrm{N+1}}{3} \quad (3)$$

It shows that if the number of nodes that do not received message is larger than a threshold, the broadcast should be done to save the total energy in the group.

The decision should be taken by the proxy, before the error recovery. However, the proxy could not know the situation of other nodes among the group, and could not compare the number of failed nodes to the threshold, either. Getting all nodes to tell the situation themselves is not power-saving, neither. The proxy could only make the decision by evaluating the communication's quality in the last phase between the satellite link and itself. When it turns to a good result, only a few nodes need retransmit. The work would be assigned to the nodes distributed in the multicast tree. When the evaluation comes to a poor result, it considers that the majority of the receivers do not receive the full message. The proxy would adopt the way of terrestrial broadcast to retransmission. Thus, the evaluation plays a vital role in local recovery. The evaluation contains the factors as follows:

- Q is the quality of communication, $0 \leq \mathrm{Q} \leq 1$. When $\mathrm{Q} = 1$, the quality achieves the best condition.
- T is the total time cost, which starts from receiving the first packet to the end of the last packet.
- RTT is the estimated round-trip time. For the satellite condition, there is only one hop between the sender and the proxy and the satellite work in a high speed without blocks. So $\frac{\mathrm{T}}{\mathrm{RTT}}$ could be approximately regarded as the number of total packets received in the total time, including the retransmitted packets.
- C is the number of the packets in a message, which is the exact number that could be combined to the full message.

The evaluation of quality can be simplified. It is:

$$\mathrm{Q} = \frac{\mathrm{C}}{\frac{\mathrm{T}}{\mathrm{RTT}}} = \frac{\mathrm{RTT}*\mathrm{C}}{\mathrm{T}} \quad (4)$$

The evaluation connects the quality of communication to the number of failed nodes. It's reasonable for the following:

- The proxy is chosen as a node owning the best ability in a group. Thus, the quality of the link between satellite and the proxy is in the top among others.
- If the communication between the proxy and the satellite is poor, then the situation of the remaining nodes would be much more serious, which leads to a lot of nodes that fails to receive the message correctly.

To describe the procedure more accurately, we give the derivation process.

Given the following assumptions:

- The nodes in a group are distributed as a per homogeneous spatial Poisson process of intensity λ in 2-dimensional space. The group spreads in an area of circle with radius a. The proxy locates in the center of the circle, which usually happens for reason of angle between satellite and the device.
- The quality of the communication affected by kinds of several independent factors, and each factor does not have a dominant influence. Therefore, according to the central limit theorem, the quality obeys bi-variable normal distribution in the group area. The two variables refer to the longitude and the latitude. We sign this distribution as $N(\mu_1, \mu_2, \sigma_1^2, \sigma_2^2, \rho)$, where (μ_1, μ_2) are the coordinates of the proxy, $\sigma_1^2 = \sigma_2^2 = Q$ is the quality of communication in the proxy, and $\rho = 0$, which means the two variables are independent.
- The FEC used in coding offers the error correcting capability of t bits in a packet with length d.
- The factor p' stands for the possibility of wrongly transmission in per bit in average of any time, any place and any device in the geo-satellite environment.

Then we can get the possibility of P, which means the chance of correctly receiving a packet. P can be shown as:

$$P = \sum_{i=0}^{t} \binom{d}{i} (1 - p')^{d-i} p'^{i} \tag{5}$$

Furthermore, we can get the expectation E as the number of packets sent in receiving a packet successfully.

$$E = \sum_{i=1}^{+\infty} i(1 - P)^{i-1} P = \frac{1}{P} \tag{6}$$

Thus a message which splits into m packets would have the expectation to receive E(m) packets.

$$E(m) = \frac{m}{P} \tag{7}$$

According to (5), we can get the excepted q' as the quality of communication that could successfully get the message through E(m) packets. The q' is:

$$q' = \frac{m}{E(m)} = P \tag{8}$$

To achieve the condition mentioned in equation (3), we should figure out the area in which the number of devices counts $\frac{1}{3}$ in the total amount of the group. Also the quality of communication in this area is not higher than other ones besides the area. According to the Poisson distribution in the node distributed and the bi-variable normal distribution in quality, we can get the area shown as a ring, which can be seen in Fig. 3. The radius of the inner circle is called r, which learns form the following:

$$\pi r^2 = \frac{2}{3} \pi a^2 \tag{9}$$

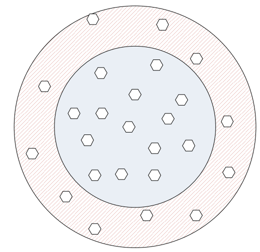

Figure 3. Location of devices in a group.

The (9) can be simplified as:

$$r = \sqrt{\frac{2}{3}}\, a \tag{10}$$

Then we can get the maximum v of quality among the ring:

$$v = f(r, r) = \frac{1}{2\pi Q^2} e^{-\frac{r^2}{Q^2}} \tag{11}$$

Thus, we can get the conclusion of the connection between (3) and (4). If $q' > v$, that means the number of the failed nodes is larger than the 1/3 of the total devices in the group, and a broadcast relay is more effective for the group. It is showed in Fig. 4. Otherwise, that means the number of the failed nodes is less the 1/3 of them, and relaying in multicast tree suits better in the group.

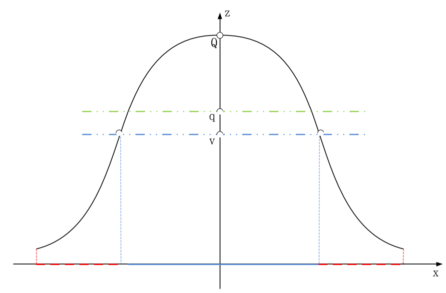

Figure 4. Relation between devices' distribution and communication's quality.

4. EXPERIMENTS

In this section, by resorting to computer simulations, a performance comparison among the classical multicast protocol TCP Peach++ (MT), the broadcast protocol based on network coding (NC) and our multicast protocol for device management (MDM) would be proposed.

The experiment focuses on two scenarios, respectively, for device management information transmission time and the energy consumption of information statistics. Due to the short length of a device management message, its transmission time and energy consumption have great chance, which easily leads to inaccurate experimental results. Therefore, we use 10000 pieces of equipment management information as a basic statistical unit to offset the contingency factors.

The statistical results of the transmission time for the message are shown in Fig. 5. We can see that the MT and the MDM methods are at a lower time consumption level with fewer nodes in the cluster. As the number of nodes in a group increases, the time consumed by these two methods also gradually increases. By the way, the time consumption in the MDM is always less than that in the MT. While the NC algorithm has been maintained at a median level, does not change with the number of nodes. Moreover, in the figure we can see that when the number of nodes in a cluster is

1000, the MDM reaches the same level as the NC and will later pass the NC.

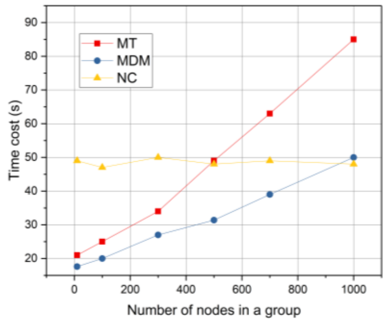

Figure 5. Time cost versus the number of nodes in a group.

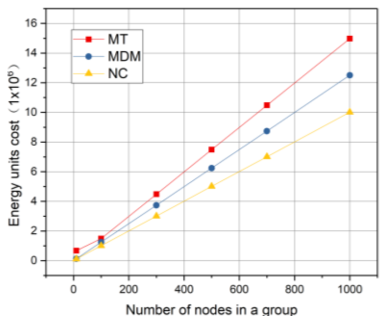

Figure 6. Energy cost versus the number of nodes in a group.

The statistical results for the overall energy are shown in Fig. 6. We can see that all three methods increase the total energy consumption as the number of nodes in the cluster increases, and the rates of increment of the three algorithms are also similar. However, the MT consumes the most, followed by the MDM, and finally the NC.

It can be seen from the experimental results that the performance of the MT algorithm in terms of both energy consumption and transmission efficiency is not as good as that of the MDM algorithm. Although the overall energy consumption of the NC algorithm in the experimental process is the lowest, and in the case of a large number of destination nodes, the transmission efficiency of the NC algorithm is also better than the MDM. However, considering in the policy delivery scenario, the situation that a large number of target nodes in a region rarely occurs. While when the number of destination nodes is small or moderate, the efficiency of the MDM is much higher than that of the NC, and the gap between the overall energy consumption is small. What's more, the NC consumes more memory resources in the device during operation. Therefore, it can be seen that in the scenario of policy transmission, the MDM has a greater advantage than the NC.

5. CONCLUSION AND FUTURE WORK

In this paper, we designed a reliable multicast transport protocol for device management in the space-ground integrated network. The protocol contains acknowledgement aggregation and local error recovery. We designed a rapidly tree-organized scheme for the frequently changed destinations in each message. Also we designed an evaluation scheme to choose an energy efficient way in communication for the optimizing. Experiments compared with other protocol shows the schemes works well. Future works will be focused on the optimization in the located and the election of the proxy node, to increase the universality.

6. ACKNOWLEDGMENTS

This work is supported by the National Key Research and Development Program of China (No. 2016YFB0800303) and the National Natural Science Foundation of China (No.61672515).

7. REFERENCES

[1] Laura, G., Antonio, P., and Sergio, P. 2007. Support of Delayed Real-Time Services over Geo Satellite Networks through a Recovery Service. IEEE Global Telecommunications Conference, 2007. GLOBECOM '07. DOI = http://doi.acm.org/10.1109/GLOCOM.2007.364

[2] Fang, J., Özgür, B. A. 2005. TCP-Peach++: Enhancement of TCP-Peach+ for Satellite IP Networks with Asymmetrical Bandwidth and Persistent Fades. International Symposium on Computer and Information Sciences.

[3] Hui, X., Shiqi, W., and Fei, H. 2005. An agent-based reliable multicast transport protocol for satellite networks, MAPE 2005, (08-12 Aug), 497–501. DOI = http://doi.acm.org/10.1109/MAPE.2005.1617957

[4] Gongliang, L., Wenjing, K. 2009. SCSRM: A Splitting-Connection Scheme for Satellite Reliable Multicast. Communication Software and Networks 2009. ICCSN '09. International Conference, 134-137. DOI = http://doi.acm.org/10.1109/ICCSN.2009.12

[5] Wang, J., Jiang, C., Haijun, Z., Yong, R., and Victor, C. M. L. 2017. Aggressive congestion control mechanism for space systems. IEEE Aerospace & Electronic Systems Magazine, *Res.* 31 (Mar. 2017), 28-33. DOI = http://doi.acm.org/10.1109/MAES.2016.150117

[6] Fabrice, H., Emmanuel, C., Cédric, B., Patrick, G., Emmanuel, D., and André, L. B. 2012. Reliable multicast transport of BGP for geostationary satellite networks. Communications (ICC) 2012 IEEE International Conference on, 3239-3244. DOI = http://doi.acm.org/10.1109/ICC.2012.636416

[7] Wei, H., Baosheng, W., Zhenqian, F., Zhu, T., Baokang, Z., and Wanrong, Y. 2015. NCSR: Multicast transport of BGP for geostationary Satellite network based on Network Coding. Aerospace Conference 2015 IEEE, 1-10. DOI = http://doi.acm.org/10.1109/AERO.2015.7119261

[8] Francesco, C., Romano, F., Tommaso, P., and Andrea, T. 2013. Optimized short message transmission for reliable communications over satellite broadcast channels. Global Communications Conference (GLOBECOM) 2013 IEEE, 2927-2931. DOI = http://doi.acm.org/10.1109/GLOCOM.2013.6831519

[9] Jiang, Z., Wu, Q., and Hewu, L. 2016. NTCP: Network assisted TCP for long delay satellite network. IEEE/CIC International Conference on Communications in China, 1-5. DOI = http://doi.acm.org/10.1109/ICCChinaW.2016.7586710

[10] Esposito, C., Castiglione, A., and Palmieri, F. 2017. Layered multicast for reliable event notification over large-scale networks. Information Sciences, *Res.* 379 (Feb. 2017), 177-194. DOI = https://doi.org/10.1016/j.ins.2016.04.002