CPM: A Congestion Control Method for Interplanetary Network

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***Abstract*—The vision of future space exploration includes missions to deep space that require communication among ground stations on ground and another planets such as mars, moons, satellites in different orbiters, asteroids, robotic spacecrafts, and specially for crewed vehicles for delivering information. These communications requires high bit rate for autonomous operations and also have several different limitations. These type of communications set as a network that is called Interplanetary Network (IPN). There are difference challenges in space communication that TCP and UDP are not able to address them such as Long propagation delay, asymmetric bandwidth, etc. In this work, a congestion method for CPM (Control Packet Mechanism) is presented. CPM deploys a pure rate transmission mechanism with avoid of congestion to increase throughput and performance.**

Keywords—Interplanetary Network; Deep space network; Transport layer; Congestion; Reliability.

I. INTRODUCTION

Interplanetary network (IPN) is a network to provide communication and navigation services for space communication and connect the ground station to space station on Moon or Mars via satellites and orbiters. It has become a major issue to be used in development of a deep space network as an Internet of the deep space planetary networks. IPN's development must address following issues such as: variable and long transmission delays, variable transmission speed, variable electromagnetic interference, impractical transmissions, asymmetrical forward and reverse link capacities Intermittent connectivity, etc.

TCP/IP cannot support interplanetary network because it cannot support intermittent connectivity, long delays, high bit error rates and asymmetric communication. There are some studies about comparison of effective of TCP/IP and SCPS (Space Communication Protocols Specification) for using in space network. Ö. B. Akan [1] studied the performance of TCP Protocols in Deep Space Communication Networks. It also demonstrates through experimental results that existing TCP protocols are not satisfied for the deep space communication requirements and urgent need for new TCP solutions.

IPN network does not have end to end links. Although, communication architectures are essentially point to point between each part of this network, such as communication between ground station and space craft. According to standardization of space link service interface, ground station for uplink accepts frames (and packet in future) and for downlink, it demultiplexes signals and sends them to control center by terrestrial network which use IP-Based protocols.

For instance, when a space craft is going to send information to ground stations it must wait to view an orbiter to starts sending information. As shown in Fig. 1, during data transmission from space craft to an orbiter, the orbiter cannot communicate with ground station. This is because of the fact that an orbiter cannot see the ground station and also a space link is not always connected. DTN (Delay/Tolerant Network) can be used to solve this problem. DTN's architecture is based on "store" & "forward" operations. DTN is also supports long propagation delay. The orbiter must store information and wait until it will view an appropriate ground stations for forwarding information. This scenario is very simple. On the other hand, assuming that there are many assets with more on demand mission, so, in future, architecture of this scenario become very complex.

IPN network is a delay tolerant network. Delay tolerant is one of the problems of IPN networks that is shared with sensor webs and stressed tactical communication. Delay tolerant networks require store and forward communication, routing algorithm cognizant of scheduled connectivity, Integral infrastructure protection.

IPN has a special and large group of networks' challenges because of different property of environments. IPN has also different links and all parts of planetary network do not have same architecture and operations. Therefore, there are different set of protocols in each section. For instance, planetary surface network (Terrestrial network) included all of networks on ground, especially networks between ground stations with other ground stations or control centers. All of networks in planetary surface network use TCP/IP protocols for

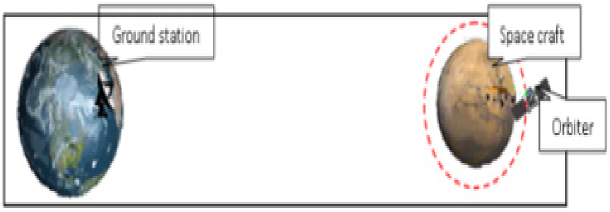

Fig. 1. Scenario of space communication.

communication and their operations are based on packet in their data link layers.

On the other hand, in communications between spacecrafts and assets or between spacecrafts and ground stations, when they meet each other the connection become established. Therefore, they must be able to save and buffer data for suitable time to delivering data to the next destination. These times are also useful to regenerate signals, make decision for best next destination and delivering data to receivers in end point of destination (find best path or routing), switch data link layer in order to match with environment [2]. Links management in planetary network is very complex, because of several types of links with different protocols, expensive and time consumption. Therefore, communications need to be scheduled between Landers, orbiters and stations and very mistake increases risks and cost [3].

II. IPN ARCHITECTURE

Most of the network architectures which are proposed for the deep space exploration are based on Internet technologies.

Scientifics believe that IPN uses five types of networks as follows [4]:

IPN Backbone Network: It provides an infrastructure for communications among the Earth, space station on planets, moons, satellite, and relay stations placed at gravitationally stable planets, etc. It includes the data links (direct link or multi-hop paths) between elements with long-haul capabilities.

IPN External Network: It consists of spacecrafts flying in groups in deep space between planets, clusters of sensor nodes, and groups of space stations, etc. Some nodes in the IPN External Network also have long-haul communication capabilities.

PlaNetary Network: It is composed of PlaNetary Satellite Network and PlaNetary Surface Network. It consists of satellites orbiting a planet, rovers and the mission elements on the planets [5]. This architecture may be implemented at any outer-space planet to provide interconnection and cooperators among the satellites and surface elements on a planet.

PlaNetary Satellite Network: The satellites circling the planets can provide relay services between the Earth and the outer-space planet as well as communication and navigation services to the surface elements [6]. Some surface elements have the capability to communicate with satellites, reporting local topology upward and receiving data and commands from satellites. The PlaNetary Satellite Network includes the links between orbiting satellites, and links between satellites and surface elements. It is composed of satellites which lie in multiple layers [7] and provides the following services [8]: intermediary caching and relay service between the Earth and the planet, relay service between the in-suit mission elements, and location management of PlaNetary Surface Networks.

PlaNetary Surface Network: It provides the communication links between high power surface elements, such as rovers and Landers, which have the capability to communicate with satellites. They also provide a power-stable wireless backbone in the planet. Moreover, PlaNetary Surface Network includes surface elements that cannot communicate with satellites directly. These elements are often organized in clusters and spread out in an ad hoc manner, e.g., sensor nodes and balloons as each of these sub networks has different challenges and so needs its own design and architecture. Hence, there requires a special protocol stack that is reasonable of all requirements of each sub networks and also it has to work with terrestrial networks to connect with terrestrial internet.

III. CPM METHOD

Control Packet Mechanism (CPM) is a reliable transfer method for IPN in backbone network. It is a Pure Rate-control method and uses a series of information packet to develop a reliable transfer method.

It supports a connection between sender and receiver such as a ground station and a space station on other planets with middle equipments such as orbiters, satellites or even rovers. In CPM scenario middle equipments such as satellites are both receiver of the last sender and sender for the next receiver. CPM as a reliable method is able to address IPN challenges. CPM has two phases with different behaviors. In the first phase CPM has conservation behavior because sender does not have information about its connection and sink. In the second phase, sender gets some information about receiver and then it will be able to calculate some parameters of connections with delay. Therefore, it changes its behavior and will continues its transmission with logical and opacity behavior.

One important parameter for a reliable method in space communication is ability to separate packet loss via errors and congestions. Congestion is occurred when traffic of link is higher than link capacity. There are some important parameters to occur congestions such as low bandwidth, bad routing algorithms, speed of processors and low buffer size of routers. Congestion causes packet lost, increases delay and retransmission, blocking of connection and finally decreases the performance. Some network methods are able to detect congestion and separate congestion from packet lost and some methods are able to avoid congestion.

In IPN we use satellites and orbiters like store and forward routers. Satellites have uplinks and downlinks with different bandwidths. Therefore, congestion may occur in both uplink and downlink if they are not matched according to the buffer size of receivers. Congestion in IPN is worse than other networks because links are expensive and have time limited. There are different methods to control congestions in IPN. Avoiding congestion or separating congestion with packet lost via errors can increase performance of network with control of data rate. For instance TP-Planet as a reliable method for backbone network is able to separate the packet loss [9]. CPM is also able to detect the congestion as well as to avoid the congestion. Therefore, it also decreases retransmissions.

All reliable transmission methods for IPN are based on packet transmission. CPM is also based on packet transmission but it will group packets in logical units as a frame. Frame will also help us to calculate some parameters of connection.

CPM uses a method like hand shake to initial the connections with sending hello packets. This mechanism also uses SNACKs instead of ACKs to reduce the ratio of reverse link and to avoid the congestion in reverse link.

A. First Phase

In the first phase to initial link, sender sends a duplicate hello packet to the receiver with a time interval to ensure the receiver receives the hello packet. The probability of loss or error of hello packet after sending twice is very low.

In the next step receiver immediately starts to send data packets in frame form after receiving hello packet. Frames are sending successively and they might have different sizes. Initially each frame contains five data packets and each data packet has 20k of data. Hence, in the first phase each frame has 100k of data. Sender also saves sequence number of packets. The reason of selecting small size for frames in first phase is that sender does not have any information about link, error links and buffer size of receiver.

Whenever receiver receives hello packet it will send its buffer size by an Information Packet 0 (InP0). InP0 is sent twice with little interval time to ensure that it is received by sender. Receiver after receives the first InP starts to calculate free buffer size of receiver with attention of size and number of sending frame using the following equation:

$$CFBS = Free\ Buffer\ Size\ in\ Inp\ (FBS) - (NIF * 5 * 20) \quad (1)$$

where CFBS is called the Current Free Buffer Size of sink and NIF is called the Number of Interval Frame. NIF consists of number of packet in interval time between sending hello packet and receiving InP0. In the first phase, there are five packets with 20k of data size in each frame. Interval frames are very important because if some of packets are lost in a frame, frame will remain in receiver's buffer and will not exist for processing until lost packets are received.

Sender calculates the sink free buffer size then set the size of its frame according to (2) and sending frame. Time of first phase is between $T = 0$ and $T \leq 2RTT$.

$$\text{Size of Frame 3} = \text{Free Buffer Size of Sink (FBS)}/3 \quad (2)$$

B. Second Phase

Second phase starts at $T > 2RTT$ (After receiving InP0 by sender). In this phase, Sink controls each frame after receiving it and sends InP with its serial sequence number to the sender. Another InPs have more information in comparison of InP0. They consist of free buffer size of receiver, list of SNACKs in theirs frame.

CPM method uses SNACK (Selective Negative Acknowledgment) to develop a reliable link. It means that retransmission occurs only for the lost packets. There are three benefits in using SNACKs instead of ACKs:

1- Number of SNACKs are very fewer than number of ACKs. Hence, CPM reduces traffic and probability of congestion in reverse path.

2- Save energy in sink.

3- SNACKs in each InP determine number of loss packet in a frame. CPM uses number of SNACKs compared to total number of packets in each InP to estimate and predict error link in a range of time according to (3).

$$EL = (Packet\ LostData\ /Packet\ in\ each\ frame)\% \quad (3)$$

Error link (EL) is an important parameter of networks. It causes packets loss, waste time and energy of nodes.

In space communication, there is not a feedback of EL because of long propagation. CPM uses (3) to estimate EL for each InPs. Sender keeps information of sending frame while InP of each frame receives in sender calculates EL and size of next frame.

List of SNACKs is also determined in each InP. Sender also keeps number of packets in each frame and it is able to calculate the Error of Link (EL).

In the next step CPM uses (4) to calculate the current free buffer sizes of receiver ($CFBS$). $CFBS$ is calculated by free buffer size (FBS) in receive InP minus sum of the size of interval packets between sending a frame and receive its InP.

$$CFBS = FBS - (\textstyle\sum_{k=1}^{NIF}(N_k * 20)) \quad (4)$$

Where NIF is called number of interval frames and N shows number of packets in each frame. Size of new frame is also calculated using equation (5) with 10% of $CFBS$ multiply by EL.

$$Size\ of\ Frame = CFBS/10 - (EL\ \%) \quad (5)$$

If $CFBS$ is exactly equal to FBS, congestion may be happened once for one of next frames and after that system goes to block out status in several times. In order to avoid the block out status the real free buffer size is divided over 10 to calculate $CFBS$ and multiplying with EL. It helps to find the best transmission rate according of link errors.

It is noted that after calculating the size of new frame, number of packets in a frame must be determined according to (6). Also, all number of data packet do not allocate to new data packet so list of SNACKs have high priority to place in new frame. Therefore, number of new data packet is calculated according to (7).

$$Number\ of\ Data\ Packet = Frame\ size\ /\ 20 \quad (6)$$

$$New\ Data\ Packets\ in\ Frame = Number\ of\ Packets\ in\ frame - SNACK \quad (7)$$

All steps will be continued until the connection is finished. In CPM method although there are high propagation delay in space communication but with using a prediction, sender is able to estimate status of link and determine frame sizes and rate.

IV. CONGESTION CONTROL

Congestion is one of important problem in networks and specially space network. In Space link because of long propagation and high distance, determining the congestion is very difficult and retransmission of packet lost require many times while because of rounding of planets and orbiters time of line of sight is very limit. Time of line of sight is effect on connection and ratio of transmission information. Hence, congestion causes loss packets and decreases performance and throughput. In the other hand, retransmission in congestion waste energy and time in sender. Hence, congestion must be detected and controlled in a way that all of lost packet must be retransmitted.

In the first phase, there are not any information and feedback about link while $T < 2RTT$. Sender receives InP0 after $2RTT$ and starts to calculate the receiver free buffer size and the size of next frame. If $CFBS \leq 0$ then sender determines congestion and stop sending next frame until receive next InPs (Sender goes to Block out status). Sender after receiving another InPs starts to calculate and to prevent congestion and also determine the size of next frames. Therefore, sender selects small size of frame to control and avoid congestion and if congestion occurs with low probability, congestion might be detected by sender. In the second phase, there would be congestion avoidance in this phase if sender calculates the free buffer size of sender to control its ratio.

A. Block Out

Block Out is another important problem in space communication and it has effect on performance. In CPM method when Error Link (EL) goes higher than 50%, it means that more than 50% of packet of frames must be retransmitted. In this status overhead of link and process of calculation is very high and transmission of frame is waste of power. Hence, sender goes to block out status and waits for determining time and then tries again and recalculates EL. This step continues while EL becomes less than 50%.

B. Frame lost and InP Lost

Sometimes frames or InPs are lost because of error link or probability problem. In this status, sender goes to timeout status and retransmission frame if after $2RTT$ of sending frame do not receive its InP. In this method, time does not waste and transmission to be continued. If lost statues occur consecutively, sender assumes that $EL \geq 50\%$ and goes to block out statues and waits until proper time.

V. RESULT ANALYSIS

In this section, we are going to validate our proposed idea in the previous section with simulation. We propose a CPM method to increase reliability in interplanetary network. Simulation of CPM needs a discrete time simulation because there are discrete event in space communications. Therefore, we used OMNeT++ 4 for our simulation since it is a discrete event simulation, modular and component-based C++ simulation library and framework.

In our simulation, there are four entries consist of ground station, tow satellites and a station on Mars as sink. Satellite is an orbiter of earth and satellite1 may be an orbiter of Mars. Assuming ground station is going to send 10GB data to Mars station and the buffer sink is equal to 10MB. If in a different situations, there are more buffers then CPM is able to increase its rate. This can be occurred with increasing the number of packets in frames although this increase is limited according to link errors in second phase. It should be also noted that error of link is variable.

In this scenario, according to CPM method in pervious section ground station starts to send data to satellite. Satellite saves information in its buffer and waits to make connection with satellite1. In the last step satellite1 sends data to Mars station. This step is continued until all data are transmitted.

There are two modules in sender on ground station as supplier and frame builder to make frames. Sending frames with 5 packets continues while InP0 is received. Fig. 2 shows communication between ground stations and satellite1 (a mars orbiter) via satellite (an earth orbiter).

Whenever InP is received in sender supplier then sender calculates the free buffer size of sink and the size of new frame. In the next step, sender frame builder builds new frame according to calculation in pervious section.

A. Congestion

Congestion is an important limitation in reliable space communication. Congestion may occur in link and reverse link when buffer of receiver is full and is not able to accept new packets. CPM uses SNACKs instead of ACKs to avoid congestions in reverse links because number of SNACKs is very lower than number of ACKs. In CPM, sender has a prediction unit. It uses information of InPs to predict free buffer size of receiver and estimate the error rate. We must consider congestion in both phases. In the first phase, selecting the correct size of frames with determining number of packets in frames is very important. Also, sending lost packets in list of SNACKs in InPs have higher priority than new packets in new sending frame. It is noted that selection of suitable size of frames in first phase of CPM is very important to control congestion. The size of packet must be at first selected based on sink buffer. It depends on equipment of satellites and stations on earth and other planets. In our simulation, sink buffer is 10MB. The results of simulations show that in CPM if size of frames is selected correctly then there are no congestions. Fig. 3 shows different range of packet size that is used in our simulation. It is clear from Fig.3 that if we select 200k instead of 20k then the higher rate of congestion is occurred and retransmission is needed. It is also noted that to avoid congestion we must keep the rate of packet size low. In

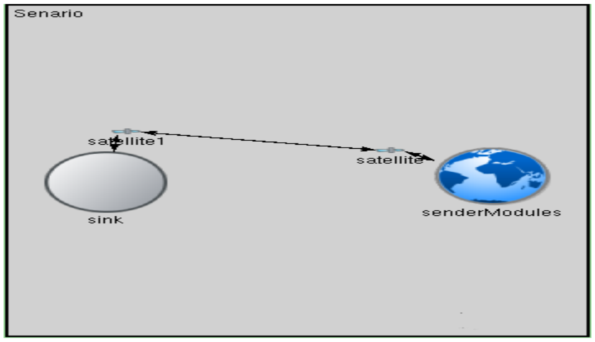

Fig. 2. Scenario of CPM simulation.

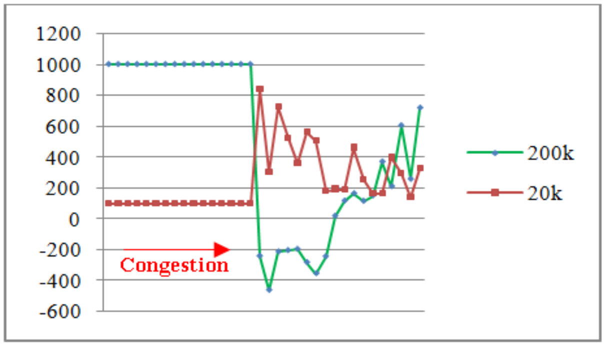

Fig. 3. Rates with different range of packet sizes.

this way the congestions and retransmission is avoided with higher rate of packet size. As mentioned, congestion means packet lost and solving the congestion and retransmitting the lost packet wastes the time and the energy for resending. In Fig. 3, there is a range of packet sizes with 10M of data of sink buffer. Number of packet that they are less than zero means congestion as well as number of lost packet.

As it can be seen, the size of packet is based on sink buffer size. Sink buffer might be increased in future if the necessary equipments are developed. CPM is flexible with the following changes. If size of buffer is decreased then the rate of transmission is decreased and the time and energy are wasted and congestion is happened in first phase so the system goes to block out status. However, if the size of buffer is increased then CPM will be able to adapt itself with these changes.

B. *Overhead*

CPM does not increase any overhead to link because it does not make any addition or changes in header of packets or any other form of sending. Also, in reverse path CPM does not make any addition in overhead. In reverse link CPM uses SNACKs and sinks buffer size instead of ACKs and does not increase rate and overhead.

VI. CONCLUSION

The vision of future space exploration includes missions to deep space that requires communication among planets, moons, satellites, asteroids, robotic spacecrafts, and crewed vehicles. This vision involves in the design and development of next generation deep space networks, which is expected to be the Internet of the deep space planetary networks and defined as Interplanetary (IPN) Internet. IPN is set of networks for developing internet to space by using space communications. Reliable data transmission is a key for developing IPN by using deep space communications for address high propagation delays, high link error rates, asymmetrical channel bandwidth and intermittent connectivity. Almost all of the protocols solve the several problems of space communications such as high BER and/or long link delay. Also, some of these protocols such as SCPS-TP or TP-Planet will solve other problems such as bandwidth asymmetry, channel efficiency and fairness.

In this paper, we proposed a control packet mechanism (CPM) to increase the reliability in space communications. Reliability are very important in space communication and IPN to control rate and to avoid congestion because link is very expensive, power is limited and time of line of sight is limited and requires scheduling. In space communication detection, separation of packet lost and congestion with long propagation delay is very important. CPM is based on frames and it has two phases. In the first phase, it initials the connection with a fix rate. In the second phase, CPM uses control packets (InPs) to determine the lost packets as a list of SNACKs and buffer of sink. It uses size of buffer of sink to avoid congestion.

CPM uses two asymmetric links between the sender and the receiver to send control packet by the receiver to the sender to control the performance. Control method is able to control and address delay, long propagation, congestion, high bit error rate and increasing the rate. Energy and complexity are other important issues in IPN.

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