Mars Planetary Rover Control Protocol

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***Abstract*— Robotics technology has revolutionized many fields. Robots are of great help in space, industries and in war. In deep space, they have wide applications in exploration field. Mars Planetary Rovers are unmanned vehicles that are designed for the exploration at Martian surface. Mars Planetary Rovers are subjected to traverse over surface of mars for exploration purpose. Mars Planetary Rover works autonomously with assistance from base stations at earth that control or command the rover remotely. This paper proposes a protocol which works at transport layer for communication between the mars rover and its earth's station. The protocol proposed can be mapped back to TCP/IP network suit.**

***Keywords*— Mars Space Rover, Transport Layer, TCP/IP and Sol**

I. INTRODUCTION

Planetary rovers are designed to explore and analyze the planetary terrains and other astronomical bodies, carrying out physical study of the environmental conditions, surrounding the surface of the planet. Mars planetary rovers are equipped with high resolution cameras, a number of sensors used for the soil and rocks analysis to get clues about the past water activity on the planet. They collect the analytical data by traversing over the surface of the planet and complete the tasks assigned to them for each sol (one Martian Day).

Mars Rovers works autonomously with assistance from the control station at earth. Mars Rovers communicates with the control station with the help of a high range and a low range antenna to get command sequences from its operators and to send the collected science data back to the earth. Another approach for communicating with mars rovers is by the help of orbiters. The rover communicates with the orbiter by the help of a UHF antenna to send the science data and to get the command sequences that has been sent to the orbiter from earth's base station.

In this paper, we will take in account the direct communication between the Mars Planetary Rover and the control station situated at earth for sending command sequences from earth. Because of immense distance between the earth and the mars, time delays in communications are extensive and they affects the communication process between earth and the mars rover. It takes up to approximately 21 minutes for a message to transmit from earth to the Mars. That is why, Mars Rovers are subjected to work autonomously but still they are controlled and directed remotely from the earth.

The protocol proposed in the paper works at the transport layer for following the TCP/IP reference model. It is a very simple protocol. Commands are sent in text form from control station at earth, the commands are stored in the payload of the data packet at transport layer. A port number associated with each command is stored in the header of packet which will make the rover able to know that what task is to perform (Fig. 1).

II. LITERATURE REVIEW

Space robots make missions possible on planetary surfaces and in outer space. They are very essential in future space explorations and researches. Human Robotics working group (HRWG) assessed the present capabilities of space robots and the future challenges for them. The assessment report pointed out the application areas that would be very effective in robots technology. More investments and research will advance the robotic technology hence providing fruitful results in exploration field [1].

Planetary rovers [2] are used to conduct geological study of a planet by traversing across the planet's surface. They work autonomously with assistance from earth, but the path to traverse over terrain is not specified by the human operators, ANN (Artificial Neural Network) is a multilayered network which facilitates the rover to choose the best path to move across the terrain avoiding obstacles and pits. This network provides better performance, low consumption of energy and generality for the planetary rovers.

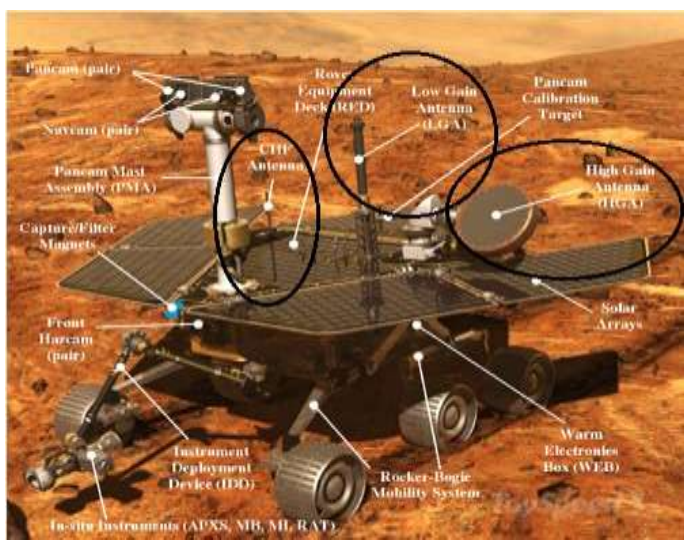

Fig. 1: The highlighted parts shows the UHF antenna used for communication by the help of orbiter, and the high gain antenna (HGA) and low gain antenna (LGA) used for direct communication with the Mars Rover

In future missions, planetary rovers will need to traverse several kilometers over terrain for exploration with little human assistance. The off-line estimation of parameters of terrain is not beneficial due to large time delays in communication from earth to mars. Rovers will be subjected to estimate the terrain parameter online to move across terrain and it will be helpful for the rovers to control and plan strategy for the given terrain [3].

Autonomous robots [4] need to face many challenges in traversing over the planet surfaces. They need to avoid obstacles and to move across the terrain safely. They need the updating of navigational information constantly to move across the planet surface smoothly and safely. As it becomes too cumbersome for the rovers to process so much information and details constantly, the navigation is divided into local and global levels. The local level is used for the removal of hazards using sensor's data and the global level decides to take that path which will be safe and obstacles free to traverse over the terrain.

The communication among many planetary rovers [5] is really important in carrying out complex tasks. Communication hardware for rovers is effective in a limited range and the movement of rovers over terrain makes this communication hard. There is need of direct line of sight communication between rovers. One approach to establish communication between rovers is to identify a group of rovers and consider some of the rovers as the communication relay, providing minimum cost for the set of links created. The relay rovers are needed to traverse some distance over the terrain to get in such a position so that communication between groups of planetary rovers is established.

To traverse over slopes and uneven terrain, information about the terrain properties are very necessary. Usually, the terrain is classified on the basis of vision and range data. Another approach to get information about the terrain properties [6] is by vibrations produced in the structure of the planetary rover due to the wheel-terrain interaction. Vibrations are recorded in an accelerator and then compared with the previous results collected to estimate the class of terrain, over which the rover traverses.

There are many approaches to determine the geographical hazards [7] which are slopes, highly uneven surfaces, etc, that come in the way of a planetary rover while traversing over a terrain. There is need to have such terrain classification approaches that should also determine the non-geographical hazards like loose sand area, etc. We can use the vibration based terrain classified mechanism to determine the non-geographical hazards by applying supervised classification techniques so that the rover can traverse over the planet surface more safely.

For a mars planetary rover, a day at Mars is full of uncertainties. The uncertainty may occur in time duration during which a rover completes its job, in the consumption of energy, the energy gained through sunlight. There is need of on-board planning mechanism which avoids contingencies that can result in the mission failure. There is need to plan advance arrangements and have back up plans to avoid contingencies so that the goal assigned to the rover would be achieved successfully [8].

Since the beginning of Mars Exploration, efforts have been made extensively to automate rover's operations. These efforts have led to a very proficient activity planning system named "MAPGEN (Mixed-initiative Activity Plan Generator)" [9]. This activity plan system provides facilities to plan, plan editing, completion of plans and many others. Before commands are given to a Mars Planetary Rover. The previous data and position of the rover are first analyzed. The command sequences for the next mission are given by using this system to facilitate the autonomous operations of rovers. This system also provide assistance to "TAP (Tactical Activity Planner)" to plan the correct activities for a given sol.

In the future missions to mars, to collect large amount of data the Mars rover needs to have capabilities of traversing over several kilometers and performing operations autonomously. While executing command sequences, the rovers can face uncertainties and unexpected happenings, it can cost wastage of time and science data while dealing with such challenges. Software is developed to facilitate the rovers to plan and execute the sequences of the program on board. If some problems occur, the rover tends to recover them by changing plan techniques, increasing rover's efficiency [10]. Techniques are developed to overcome the challenges faced by the rover to manage a stable and efficient system of planning and execution of command sequences.

Use of multiple robots in a space mission or planetary exploration is advantageous. We can reduce the size and weight of the robots and we can distribute the tasks between them increasing the efficiency of the robots. When the robots work in a coordinating environment, there is need to plan and coordinate their paths to traverse over the planet surface. A static wireless network is designed to generate a high level plan for computing the paths of robots [11]. It provides a safe and efficient path for the robots to traverse over the surface avoiding obstacles, deadlocks and collisions.

The planetary exploration processes imposes constraints on the control of the rovers, different from the other unmanned robots. Autonomous control is very essential for the rovers at far planets. The biggest challenge for the autonomous rovers [12] is uncertainty, uncertainty in the time taken to complete a task, in data storage, in the consumption of energy and the change in environmental factors. The objective is to achieve maximum science tasks and to increase the capabilities of autonomous rovers. Approaches are designed for decision-theoretical based control of the planetary rovers to achieve the level of autonomy which is required to accomplish the tasks more efficiently.

III. MARS ROVER CONTROL PROTOCOL

It is not possible to control a rover remotely all the time from base station at earth because of the time delays in the communication. Control station at earth establishes connection with rover for a short time period in a sol. Command sequences are sent to the rover specifying its tasks for the sol. After the rover has completed its tasks, the transmission is

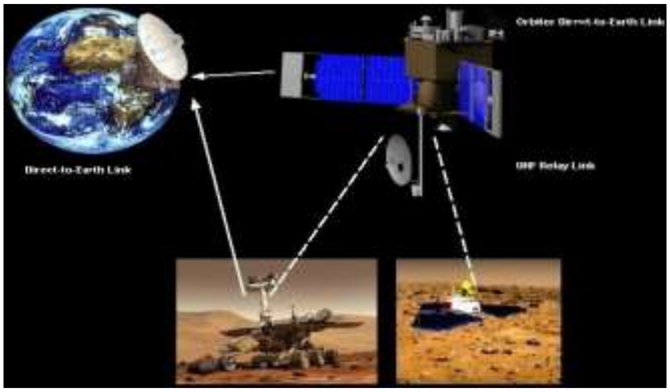

Fig. 2: Direct communication and communication through rely with Mars Rover

reversed back, the rover sends back the analytical results obtained from exploration and the science data collected. Mars rovers use the store and forward mechanism in their communication environment. First, they get the command sequences from earth and after the transmission is ended, the rover performs the given tasks autonomously.

The protocol proposed in the paper works on transport layer. It takes the commands from the application layer in the text form at the sending side, the commands are then stored in the payload of data packet. A socket number associated with each command is put in the header of the data packet and then the packet is sent to network layer. At receiving side, the rover gets the command and acknowledges the task to be performed with the help of the port number associated with the command at transport layer, further the command is sent to the application layer at receiving side.

The pseudo code for the communication at both sending and receiving side transport layers can be given as:

At sending side:

Transport Layer:

Get command from Application Layer
Store command in the payload
Put port number associated with the command in header of packet
Send the packet to Network Layer

At receiving side:

Transport Layer:

Get the data packet from Network Layer
Get the command information from the port number in the header
Send the command to Application Layer

In this way, command sequences are sent from control station to the mars planetary rover. This whole protocol design can be implemented through a simple program in C++ language. The next portion will give you the implementation of this protocol at the transport layer of both sending and receiving sides.

IV. IMPLEMENTATION

Let's implement the protocol design using data structure of hash table and link list. The head pointer of the link list in physical layer is named as "comma". We have defined a global class named "Rover_Commands", this global class is defined in a header file. It contains a four bit sigma code for every command and a four bit sigma code for port numbers associated with every command. The global class contains the hash table for the commands and the port number of each command associated with it.

The sigma combinations defined for each command and the port numbers are as follows:

Sigma = {@, #, &, %}
Sigma combinations for commands:
%%%% = Port of Analyzing soil texture
@@@@ = Port of Taking images of terrain
= Port of Taking panoramic data
&&&& = Port of Taking microscopic images of Freshly discovered layers of a rock
@@@# = Port of sending data to orbiter
@@@% = Port of collecting airborne dust
@@@& = Port of traversing to a specific site
@@## =
@@%% =
@@&& =
@#%& =
#@%& =
%@#& =

The empty slots of sigma code represents that we can add more services as per our needs. We can produce many combinations of this four bit sigma code for the new services added.

The function "Control_Transport_Layer_Data" receives the data from Application layer and processes it.

```
void Control_Transport_Layer_Data ()
  {
    node *ptr = a1.check_comm(str);
    comma = new node;
    comma->command = ptr->command;
    comma->next = NULL;
    node *ptr1 = new node;
    ptr1->header = ptr->next->command;
    ptr1->next = comma;
    comma = ptr1;
    ptr1->command = ptr1->header;
  }
```

check_comm() function is used to get the command and the port number associated with it from the global class, putting port number into header and the command in the payload and send it to the Network Layer. The "*ptr' gets the command from the hash table. 'a1" is an object of global class to access the check_comm() function defined in the global class. The "*ptr1" first gets the header and attach it before the payload.

The function that sends the data to the network layer is as follows:

```
node* get_tpdu()
   {
      return comma;
   }
```

From Network Layer, the data packet is forward to Data link layer and then to physical Layer attaching header and trailer at each layer.

At the rover's side, the listening port is always on to get the command sequences from the earth. TCP/IP reference is followed throughout the communication. At this side, data packets are received and from pass from Physical Layer, Data link Layer to Network Layer, each layer detaching herder and trailer of the sending side.

The head pointer at the receiving side is named as "data" and the function receiving data from the Network Layer is "Rover_Transport_Layer_data".

The function can be demonstrated as follows:

```
void Rover_Transport_Layer_data ()
   {
      node *ptr;
      ptr = t1.get_tpdu1();
      data = new node;
      ptr = ptr->next;
      data->command = ptr-> command;
      convert2comm (ptr->command);
   }
```

"get_tpdu1()" is the function defined in network layer to get the data packet from Network Layer. "*ptr" is the local pointer which gets the command from the data packet. Port number is detached here after identifying the specific task. "t1" is the local object of Network Layer through which the member function "get_tpdu1" is accessed. The function "convert2comm" is the function which gets the command from the hash table associated with the four bit sigma code of command.

The command is then sent to the Application Layer. The rover stores the command sequences and after the communication is ended. The rover performs the specified tasks autonomously. In this way, the commands are sent to the Mars Planetary Rover from control station at earth to achieve specific science goals.

V. HOW IT WORKS

The communication is initiated from the control station at earth. As there are two ways to communicate with the Mars Planetary Rover, either by direct communicating with the Mars rover or by the help of the orbiter. We have taken in account the direct communication with the rover so far.

After establishing a secure connection between the base station and the Mars Rover, command sequences are sent to Rover specifying the goals for the rover to be achieved for the given sol.

Both low gain antenna and the high gain antenna use X-Band beams. They are used to communicate with the control station at earth directly. The low gain antenna (LGH) is a unidirectional antenna and transmits the data at the slower rate.

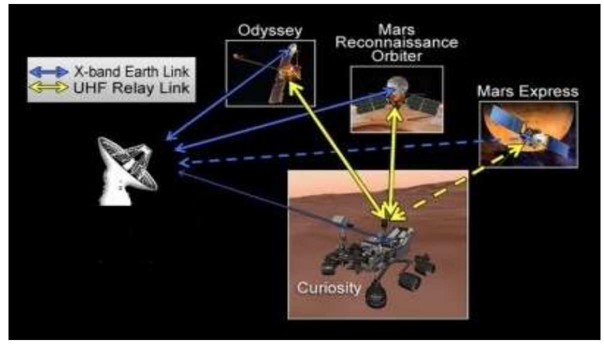

Fig. 3: The direct communication and the communication through orbiters with Mars Planetary Rover

The high gain antenna (HGA) is directed and executes communication sequences more efficiently and at high rate. The high gain antenna is steerable and can direct to any antenna on earth

Command is entered in the text format and the command is sent to the application layer. From application layer, the command is sent to the transport layer. The transport layer put the four bit sigma code associated with the command in the payload of the data packet and the appropriate port number associated with the command in the header of the packet and transfers it to the network layer. From the network layer, the data packet is sent to the data link layer and then to the physical layer. From the physical layer the data packet is uplinked on the transmission channel established between the antenna at the control station and the antenna mounted on the Mars rover.

At the rover's side, the data packet is transferred from physical layer to the data link layer, data link layer transmits the packet to the network layer and network layer further transfers the packet to the transport layer. At transport layer, the layer converts the sigma code of command in the format that the processor understands and identifies the job to execute by the port number associated with it. The command is then sent to the Application layer from where the command is stored in the memory of the rover. The rover stores the command sequences and performs the tasks specified autonomously after the communication is ended.

VI. CONCLUSION

This paper presents a simple Transport Layer protocol for controlling and directing a Mars Planetary Rover from earth. It allows us to send command sequences to the rover in a very simple way. This protocol works on TCP/IP reference model, we can use the same approach on Deep Space Network model as well.

VII. FUTURE WORK

The protocol proposed in the paper works on the Transport Layer but we can design it for the whole TCP/IP network suit. The protocol works for the TCP/IP reference model, but we can map this protocol on DSN (Deep Space Network) network as well. This protocol is used for the direct communication between the control station and the planetary rover. We can also use the same approach for the communication between the planetary rover and the orbiters or for the controlling the functions of the orbiters right from the base station at earth.

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