MANET and Spread Spectrum based Multi-Rover System

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Abstract—Presently space exploration missions involve the usage of upto maximum of two rover systems. A single rover system requires the investment of more time in exploration and mission completion. A dire necessity to look for alternative energy sources and other resources, the pursuit of knowledge and search for the existence of extra terrestrial life, are the motivations for humans to undertake such missions on a large scale in the near future. Communication between individual rovers and the Lander along with their tracking and positioning is a challenging task and we explore an indigenous way of overcoming this problem. An Enhanced AODV with dynamic routing is implemented to overcome the constraints of Destination Sequenced Distance Vector(DSDV) and latency of Ad-hoc On Demand Vector(AODV). A more viable approach for tracking and positioning is using spread spectrum technique and triangulation method. This paper brings out an indigenous way of overcoming these problems using MANETs by combining the advantages of both AODV and DSDV, thus increasing the performance of the system.

Keywords: Multi-rover, Base station, Control station(on Earth), MANET, Path Planning, Spread Spectrum, Triangulation.

I. INTRODUCTION

Planetary missions including to those regions of space which have conditions inhospitable to humans have been in the process of planning and implementation. This ranges from missions to the moon for searching life on exoplanets. Ground based observatories which utilize optical telescopes, radio telescopes and other devices have limitations, in terms of filtering and interferes due to distortion of electromagnetic radiation by the Earth’s atmosphere. The next level would be space-based astronomy, where the device is placed outside the Earth’s atmosphere which allows observation of the frequencies of the electromagnetic spectrum that are not attenuated, namely X-rays, Ultraviolet. The next ambitious step in the process of taking the exploration forward would be launching probes to these worlds and setting foot into the actual terrain (or space) of these regions. Several missions to explore the Earth’s moon, other planets and their moons are already in the pipeline. Communication is a vital component of these missions. Mobile Ad-hoc Network(MANET)[1][2] is a well-tested, robust and reliable system which is used in such environments.

Chandrayaan-1[3], India’s first unmanned lunar probe, was launched in 2008 from Sriharikota by the Indian Space Research Organization (ISRO). In Chandrayaan-1, Goswami et.al describe the carried payloads of instruments for Terrain Mapping, Lunar Laser Ranging, a moon impact probe, the moon mineralogy mapper (M3), i.e. a total of 5 Indian Payloads and 6 payloads from ESA, NASA JPL, and Bulgarian Academy of Sciences etc.

Exploration of the solar system will largely rely on robotic means at least for the forthcoming decades. Rovers and Orbiters can be used to gather data in space. A rover (or sometimes planetary rover)[4][5][6] is a space exploration vehicle designed to move across the surface of a planet or other astronomical body. Some rovers have been designed to transport members of a human spaceflight crew; others have been partially or fully autonomous robots. Rovers usually arrive at the planetary surface on a spacecraft cum Lander. The benefits offered by rovers over orbiters and stationery-Landers are:

- Elimination of the need for humans to enter hazardous territories.
- Studying the actual conditions on a planet instead of observing it from a distance.
- Large areas and regions inaccessible to the orbiters can be reached.
- They can be directed to study interesting features, and can place themselves in regions to prevent themselves from being exposed to extreme environmental conditions.
- They can be made to collect and analyze samples from the environment and also produce results of these analyses.

Temperature and pressure extremities, radiations, efficient usage of power, ability to survive for the maximum possible time must be some of its qualities. Their advantages over orbiting spacecraft are that they can make observations on a microscopic level and can conduct physical experimentation.
Disadvantages of rovers is their higher chances of failure due to landing and other risks, and their limitation to a small area around the landing site. Rovers which land on celestial bodies cannot be remotely controlled in real-time since the speed at which radio signals travel is far too slow for real time or near-real time communication. These rovers are capable of operating autonomously with little assistance from ground control. The rovers still require human inputs for control as far as navigation and data acquisition are concerned. Identification of promising targets, driving them to the same, positioning of solar panels to maximize the energy received are some of the manually controlled actions. As far as the present day technology is concerned, a maximum of two rovers are sent which are manually controlled as stated above, either from the Lander, or from the base station on the Earth. A failure of the rover to perform a specific task or the job at hand, would lead to the total failure of the mission. This situation is well known as the Single Point Failure.

II. RELATED WORK

A. Vehicular Ad Hoc networks (VANETS)

An Intelligent Transport system (ITS) is one which makes use of information and communications technology. ITS can help solve problems related to traffic congestion and safety. They usually deploy communication systems in the form of satellite location (used in GPS), mobile telephony or wireless networks. Vehicle Ad-Hoc Networks or VANETS[7] are a form of Mobile Ad-Hoc Networks with the difference being that the mobile nodes are vehicles. The nodes or vehicles can move around with no boundaries on their direction and speed. This arbitrary motion of vehicles poses several new challenges. In these networks, vehicles are equipped with a communication system that allows them to exchange messages with each other and also with roadside network infrastructures. The nodes move fast and these movements are restricted by road topology, traffic control mechanisms, speed etc. The vehicle acts as a transceiver i.e. sending and receiving at the same time while creating a highly dynamic network.

There is a continuous variation in parameters like traffic-density, atmospheric conditions etc. The applications of these networks include collision warning, driver assistance, cooperative driving, map location and automatic parking. In a collision avoidance system, when a collision has already occurred, warning messages can be issued to prevent pile ups and also alert emergency medical personnel. The Mobility Model governs the set of rules that define movement pattern of nodes in ad-hoc network. Network simulators can then, by using this information, create random topologies based on nodes position and perform some tasks between the nodes. Performing real-time VANET experiments however is impractical as the cost of the experiment would be too high. Network simulators are used for the simulation of both the communication protocol layers and realistic simulation of the vehicles mobility to estimate movement and position of the entities[8]. The simulators that are currently being used are Ns-2 and SUMO (Simulation of Urban Mobility)[9]. Ns-2 is a discrete event simulator, used extensively for network protocol simulations including wired and wireless to imitate real time implementation scenarios. Ns-2 has an executable command ns which takes on input argument, the name of a Tcl simulation scripting file. In most cases, a simulation trace file(extension .tr) is created, and is used to plot graphs and/or an output for the Network Animator (NAM) is created. NS2 consists of two key languages: C++ and Object-oriented Tool Command Language (OTcl). While the C++ defines the internal mechanism of the simulation objects, the OTcl sets up simulation by assembling and configuring the objects as well as scheduling discrete events. The C++ and the OTcl are linked together using TclCL.

Simulation of Urban MOBility (SUMO) is an open source, highly portable, microscopic road traffic simulation package designed to handle large road networks. It supports collision free vehicle movement, variety of vehicle types, multi-lane streets with lane changing and also many other network formats may be imported. SUMO allows one to create a map manually by creating .xml files, or randomly generating a map using one of the built in functions.

III. PROPOSED MANET AND SPREAD SPECTRUM BASED MRS

A. Multi-Rover System(MRS)

The probability of a mission failure is very high when a single rover is used. To help reduce the risk involved in the mission and maximize the recovery of data, an idea of a multi-rover system design which is autonomous and completely self-functional, is proposed. In a multi-rover system, each of the rovers is independently structured with sensors, processors and actuators. They are capable of interacting with each other to fulfill the global goal. A Multi-Rover system has many advantages. It can execute tasks beyond the scope of a single rover. It can complete tasks faster and yield better results in a hazardous environment, as even if one of the rovers fail, the others can act as a substitute. The data acquired by the rover can be recovered by the rest of the rovers and stored with them or transmitted back to the main station, thus adding to the advantage. The Lander may carry up to 10 rovers. This allows advantage. The Lander may carry up to 10 rovers. This allows coverage of a much larger geographical area in a more efficient way, saving precious financial resources, time and energy. This system also allows the inclusion of more rovers once the mission has already begun. New rovers from a second Lander can be added to the system as and when the requirement may increase. To increase the efficiency of the system, a strong network should be established between the rovers[10]. All the rovers, although autonomous, are connected to each other and are capable of receiving as well as transmitting the data to one another on demand. This feature can be implemented by establishing a Mobile Adhoc network (MANET) between the rovers. The data collected is either passively or actively stored; in which case it will be buffered and forwarded to the base station provided it is in the coverage area. If not the latter option is enabled. It further increases the efficiency of the
mission; if some rovers go out of coverage range to an extent of nonrecoverability, they can continue their work until it is recovered, substantiating the independence[11].

A fully autonomous rover has the ability to:

* Gain information about the environment.
* Work for an extended period without human intervention.
* Move either all or part of itself throughout its operating environment without human assistance.
* Avoid situations that are harmful to people, property, or itself unless those are part of its design specifications.

An autonomous rover may also learn or gain new capabilities like adjusting strategies for accomplishing its task(s) or adapting to changing surroundings.

B. Communication System

The backbone of a multi-rover system is its robust and reliable communication system. The most efficient communication system that can be used in such an environment is a wireless ad-hoc network. The multi-rover system can be viewed as a multi-node system, wherein each node is fully functional and autonomous. The rover system constitutes a system of mobile routers (nodes) and associated hosts (nodes) connected by wireless links, the union of which form an arbitrary graphical topology. The nodes (rovers) are in continuous motion, mining the surface for information, thereby requiring the use of mobile ad-hoc network or MANET. The mobile rover system constitutes a dynamic topology, thus requiring an efficient routing protocol, capable of faithful exchange of data. The routing protocol should be able to dynamically furnish the nodes with the shortest path so as to forward the information packets appropriately between the source and destination. Destination Sequence Distance Vector (DSDV), is a table-driven protocol, where each node of the network maintains a routing table for the transmission of information packets and also for the connectivity with different nodes. The routing table provides key information such as source and destination ID, metric and a sequence number originated by the destination node. Every time a node enters a network, it advertises itself by flooding the network with its whereabouts. Since the entries in the table change very quickly, the broadcasting should be done frequently to ensure that every node can locate its neighbors and calculate the number of hops required to establish the shortest path to the destination, through which nodes can exchange data even in the absence of a direct communication link. The routing tables contain the sequence number created by the transmitter and the latest destination sequence number used for taking forwarding decisions. This new sequence number is updated to all the hosts in the network which decides on how to maintain the routing entry for that originating mobile host[12].

The reactive or on-demand ad-hoc network is a self-starting network wherein each node acts as a specialized router, where the routes are obtained as and when needed. They maintain a routing table with information entries of each neighboring nodes and two separate counters; a node sequence number and a broadcast ID. When a source node has to communicate, it increments its broadcast ID and initiates path discovery by broadcasting a route request packet to its neighbor. The algorithm makes sure that only the nodes in the active path maintain information about the route. If an acknowledgement packet is not received for a request packet forwarded, the routing information recorded in routing the table is deleted. This reduces the power consumption of the system to a considerable extent. Broadcasting in DSDV is very frequent and periodic, as compared to AODV, which uses only HELLO messages to maintain the routing table updates. In DSDV, sending the data to the destination needs no new route to be found, where as there is a huge latency for doing so in AODV. DSDV cannot handle mobility at high speeds due to the lack of alternative routes, making the existing routes in the table stale, whereas in AODV they are found on demand. The Enhanced AODV is a routing algorithm having the basal features of AODV, and adapting features of DSDV of updating the routing table at a rate higher than that of AODV, having a better power efficiency than the AODV. This protocol also uses broadcasting messages for mapping all the nodes of the network, instead of the regular HELLO message sent to neighbors. However, only the well-established paths are recorded, whereas the rest are deleted, which is a property of AODV.

The overhead on the network system is optimized as the number of nodes is comparatively small. Also, the bandwidth is effectively utilized because continuous updates broadcast like that of in DSDV are not required. In a multi-rover system, the rovers may be at a large distances from the each other and from the Lander, which here acts as the server. One possible solution is by using a separate rover-rover and lander-rover protocol Each rover may have different neighbors at different instances of time. However, the connection between each rover and the Lander is a direct connection. Thus the DSDV protocol will suffice as the path is known. Communication between each individual rover can be maintained by an AODV protocol, which keeps refreshing the routing table with current neighbors. The usage of separate protocol will however lead to large discrepancies while repeater nodes or intermediate rovers are required to be used, in case the source rover is very far off from the destination Lander. Thus, the Enhanced AODV with a higher updating rate of the routing table, is more efficient in the present scenario. In case of introduction of a new set of rovers, this protocol can be used between them and the same base station as the updating of the routing table (not necessarily on demand) will give the information of the new rovers and thus include them dynamically to the system for communication.

The flowchart depicts the process of route discovery and storage since the nodes are less prone to dynamic changes (physically). The routes are stored as and when a new (better) route is discovered. These routes are used for communication between nodes, thus reducing the latency. This also reduces energy as continuous broadcast for table is not required. Thus, using this enhanced protocol, we are able to overcome the disadvantages of both, the DSDV and AODV.
C. Tracking and Positioning

Estimation of the position of a mobile rover in a real time environment is one of the most challenging tasks. Position of the robot can be calculated with the help of onboard encoders and knowledge of the initial location. However, the measurement provided by this means is not very accurate and thus not reliable. For better accuracy, measurements obtained by sensors set on a robot are used to correct the information provided by the encoders.

Knowledge of the physical environment makes it easier for the measurements by using some well-known algorithms (such as the Kalman filtering process). However, when the environment is unknown, positioning and mapping should take place simultaneously. This is better known as SLAM (Simultaneous Localization and Mapping).

In order to localize and approach scientifically interesting targets or areas, the robots must employ an on-board highly sophisticated autonomous navigation system.

The rover has to fulfill these tasks to be successful and efficient:

* Perception: Viewing the world and interpreting what it sees.
* Localization - Keeping track of robots position.
* Local Navigation - Making sure the robot doesn’t tip, drive into holes or bump into obstacles.
* Global Path Planning - finding the fastest and safest way to get from start to goal.

Organization can either be centralized, where the global goal is known only to the top of the pyramid, or decentralized, where each individual robot works on local information. A combination of the two is implemented for optimum results.

1) Path Planning: In mobile robot navigation, a grid-based representation of the environment is obtained and the aim is to obtain a path from an initial point to a desired location. Path planning[13][14] in a robot requires the generation of an optimized path, where in collisions with static and dynamic obstacles can be avoided. The field of path planning borrows heavily from experience in other fields like computer networking, artificial intelligence, computer graphing, and decision making psychology. Although it is not the only type of cognition required, path planning is definitely a key component of autonomous intelligence. Path planning and specifying the path at which the robot has traversed can be mapped to future reference. The mapping will provide information about the distance from point to point and the best path between them alike to the metric path planning operation in GPS system.

For the representation of the path a configuration space or c-space can be established. The c-space contains the information about surrounding word and the configuration of the robot at that point. With the inputs from the external environment, possible configurations can be estimated.

In representing the world for robot path planning, a continuous or discrete search space can be used. Path planning means finding a continuous trajectory which navigates this space. It is more difficult to do planning in a continuous state space, as the mathematics involved becomes complicated. The continuous state space is more often used for reactive obstacle avoidance rather than for global path planning where the complexities overwhelm its usefulness.

D. Position Tracking Using Spread Spectrum Communication Technique and Triangulation

This technique uses position tracking system that is performed by radio frequency (RF) devices. Advantages are ability to penetrate through objects, walls and the human body, resistant to masking (hiding), easy to construct, and scalable to both large and small areas. It exhibits two important characteristics in obtaining the position of the rover. The first is excellent ranging ability which allows accurate measurement of distance between two points. The second is code division multiplexing (CDM) which allows multiple transmitter-receiver pairs to cooperatively share the same frequency at the same time, allowing for several sensors to be used on rovers.
E. Position Tracking in a Real Environment

Spread-spectrum[15] means, transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information. The band spread is accomplished by means of a code which is independent of the data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery. Triangulation, using the principle of CDMA spread-spectrum ranging technique, of an unknown position is accomplished by using synchronous transmitters and receivers. The receiver must calculate its position using the triangulation method similar to the Global Positioning System.

Spread-spectrum has two distinct advantages over conventional communications methods: accurate ranging commensurate with code sequence speed and code division multiple access (CDMA). These advantages bring the ability to track position to millimeter accuracies while allowing multiple transmitters to use the same frequency band at the same time. The accuracy of the system is dependent upon the frequency, coding and signal processing implementation.

The spread-spectrum position tracking system breaks down into two major components: 1) Stationary position transmitters 2) Receivers on the rovers.

The transmitters are not very complex in design, the only critical design issue being timing synchronization. All transmitters must transmit their precise code sequence at the same time. These transmitters are stationary beacons which can be set up on the land surface at predefined locations by launching them on to the surface while the probe is in orbit.

The receiver calculates its position using the triangulation method. This requires that each receiver has a processor and a clock. Once the position of the receiver is known, it sends the position data to a central processor which collects it and forwards it to the receiver.

Triangulation of an unknown position is accomplished by GPS satellite transmission and the received signal propagation time delay determines the distance. The signal delay is proportional to the signal distance travelled. The range determined due to the presence of a clock error is termed as pseudo-range. Each transmitter provides one dimensional range measurement. Taking even the time parameter measurement into account along with these, the coordinates of the rover can be represented as (a, b, c, τ). The tetrahedral arrangement of the transmitters is generally preferred but since such an arrangement is not feasible in space the practical implementation is done by placing the transmitters in the same plane. The transmitters are referred to as T1, T2, T3 and T4 respectively in this scenario (figure 2) and the lander being one of the transmitters, say T1, is considered as origin. Let the coordinates of the receiver be the vector (a, b, c, τ), and that of the transmitters be T1(x1, y1, z1), T2(x2, y2, z2), T3(x3, y3, z3) and T4(x4, y4, z4). The ranging equations thus obtained are:

\[(x_1-a)^2 + (y_1-b)^2 + (z_1-c)^2 = (PR_{1-τ}c)^2\]
\[(x_2-a)^2 + (y_2-b)^2 + (z_2-c)^2 = (PR_{2-τ}c)^2\]
\[(x_3-a)^2 + (y_3-b)^2 + (z_3-c)^2 = (PR_{3-τ}c)^2\]
\[(x_4-a)^2 + (y_4-b)^2 + (z_4-c)^2 = (PR_{4-τ}c)^2\]

where PR1, PR2, PR3 and PR4 are the pseudo-ranges obtained from the receiver and τ is the receiver clock error and c is the velocity of light 299,729,458 m/s. These equations aid in the solving for the unknown four dimensional coordinates (a, b, c, τ) of the rover.

If clock error τ becomes negligibly small, then a combination of any three of the above equations may be used to obtain the unknown rover coordinates and the most accurate measurement of position may be obtained by minimization of error.

\[\begin{align*}
(x_1-a)^2 + (y_1-b)^2 + (z_1-c)^2 &= (PR_{1-τ}c)^2 \\
(x_2-a)^2 + (y_2-b)^2 + (z_2-c)^2 &= (PR_{2-τ}c)^2 \\
(x_3-a)^2 + (y_3-b)^2 + (z_3-c)^2 &= (PR_{3-τ}c)^2 \\
(x_4-a)^2 + (y_4-b)^2 + (z_4-c)^2 &= (PR_{4-τ}c)^2
\end{align*}\]

If clock error τ becomes negligibly small, then a combination of any three of the above equations may be used to obtain the unknown rover coordinates and the most accurate measurement of position may be obtained by minimization of error.

F. Memory System

A special purpose memory system is required on board for all the rovers, to overcome any of the communication or system failures that may occur on the system. Each rover has upto at least a half hour of data backup. This kind of backup system allows for data retrieval even if a communication module on the rover has been damaged. If a rover gets out of the signal transmitting or receiving range, the data is stored on the on-board buffer memory till it is able to transmit it, being able to work without the assistance of the base station. The path tracking algorithm also assists the rover that has gone out of range to come back into the broadcasting range. In case of damage to one of the rover, rendering it incapable of movement, a peer to peer transmission system may assist the retrieval of data and sending it to the base station. Along with this, a physical data recovery system is also available where one of the neighboring rovers may be able to retrieve the data by physical contact. All safety precautions are taken when an important mission of this stature is taken up.

IV. SIMULATION AND RESULTS

The DSDV connection between the rovers and the lander is simulated Network Simulator-2 (ns-2.34) with 12 mobile nodes, 0 to 11 (rovers) and a Lander node 13. The graphical representation of this simulation is shown with Network Animator (nam-1.14). The snapshots of the same are shown by figures 4 and 5.
Fig. 4. SNAPSHOT OF SIMULATION OF COMMUNICATION BETWEEN LANDER AND ROVERS IN NETWORK ANIMATOR (NAM)

Multiple, identical rovers possess enough intelligence to perform useful tasks under well tested protocols, AODV and DSDV allow for decreased of their existing resources. An optimum combination of two suitable for multiple rovers. It enhances their ability to work independently without adding a constraint on their degrees of freedom and ability to explore spread-out areas. With the help of the tracking data, the rovers can be intelligently reassigned tasks if one of them has stopped function completely. The tracking algorithms not only establish a safe path of travel for the rover but can also generate valuable data on locations, obstacles, nature of terrain for surrounding rovers. Spread spectrum technique is easy to put into use and secure for sending and receiving the surveillance data. Future work involves using some of the independent nodes to act as mini-base stations to transmit the data acquired locally, without requiring to transmit to the main base station. The development of Dynamically changing AODV will aid such kind of missions by making communication systems customized. The usage of different maneuvering techniques like hovercrafts[16] instead of land based rovers will help save energy and improve mapping time.

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