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RESEARCH ARTICLE

Information dissemination algorithms in space deployed ad hoc networks

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Abstract

Based on recent trends, in the next few years there could be a lot of cheap devices placed on the surface of different luminaries like the planet Mars instead of sending one or two expensive space-probes. If there are many cheap instruments on the surface of a planet, it is worth using ad hoc networks. For such a network, using energy saving and robust solutions is crucial. We need a local and automatic coordination because of the far distance and the delays appearing in the interplanetary communication. We have dealt with a special type of ad hoc networks and constructed an information dissemination algorithm called SPIO which can collect and exchange data on a distant planet faster than the nowadays used point-to-point systems.

Keywords

ad hoc networks · information dissemination · space communication · space research

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1 Introduction

In the last few years it has become more popular for the space agencies to send not one expensive, but more cheap space-probes to planets in the solar system. Based on recent trends, in the next few years, there could be a lot of cheap devices placed on the surface of different luminaries like the planet Mars or the moons of Jupiter and Saturn. If there are many cheap instruments on the surface of a planet to perform several tasks, then instead of using point-to-point communication systems, it is worth using ad hoc networks. For example, we could place many cheap sensors forming an ad hoc network on the surface of Mars and collect regularly the measured information using a rover or a robotic plane or a satellite instead of using one immobile probe or slow moving rover.

It is easy to understand that we cannot use a wireless network built around a fix infrastructure in this kind of environment because of the huge cost. It is worth using ad hoc networks where the collection of wireless mobile nodes forms a temporary network lacking the centralized administration or standard support services regularly available on conventional networks. For such a network, using energy saving and robust solutions is crucial. The cost of small devices should be kept as low as possible which supposes easy engineering solutions for the software and hardware. There is no possibility to repair a failed device except in the far future using a high-cost manned mission. Every percent of the battery is important for using the device, because manual recharge is impossible. We need a local and automatic coordination because of the far distance and the delays appearing in the interplanetary communication.

In the last years we have dealt with a special type of ad hoc networks on Earth, where neither central-control nor addressing exists and the information should be disseminated fast, before the period of validity expires and the entire operation depends on the effective spreading of the information as the system has a very special nature [1], [2]. We constructed an information dissemination algorithm named IOBIO (InfOrmation Dissemination Algorithm for BIOlogically Inspired Networks) [3]. In this article, we present its space adapted version (SPIO) which can collect and exchange data on a surface of a distant planet

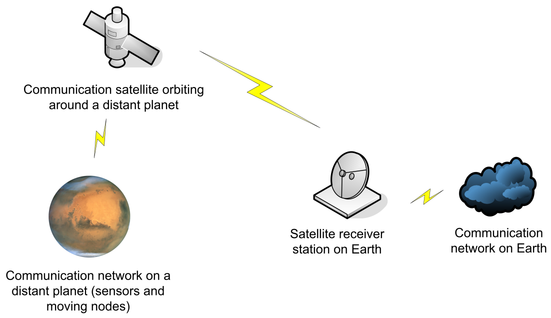

Fig. 1. Overview of a possible communication network connection between Earth and a distant planet like Mars.

faster than the nowadays used approaches.

The overview of a space-based communication network is illustrated in Fig.1. The sensors and moving nodes form a communication network on a distant planet. They can be placed either on the surface or in the atmosphere of the distant planet. Measured data are transferred to Earth via a communication satellite orbiting around a distant planet. The data are transmitted into a communication network on Earth, and are processed at Earth-based end-terminals. In our paper we focus on only one part of this arrangement – to the communication network on the surface of a distant planet.

The rest of this paper is organized as follows. In the next section we present some related works which deal with handling message forwarding or routing in space communication. In Section 3, we introduce our approaches for information dissemination on the surface of a distant planet. In Section 4, we introduce the properties of the SPIO algorithm. We conclude our work in Section 5.

2 Information dissemination in space communication

The exploration of the Solar System has almost a 50-year-old history. At first we used only point-to-point communication solutions – sending orders and receiving data from the space probes. Later rovers were placed on the surface of a planet (like the Spirit and Opportunity on Mars) and landing probes were sent to a planet (like in the Cassini-Huygens mission). These special units were reached by another space probe which was orbiting around the Mars or fly-by the Saturn.

The first artificial satellite, the Sputnik 1 was launched in 1957 with a mass of 83.6 kilograms [4]. We were able to create larger and larger satellites, like the XM-3 commercial radio satellite with mass of 2800 kg in 2005. However, the miniaturization appeared in this field like the Hungarian Cubesat, the Masat-1 with mass of 1kg [5]. In 2011, a Sprite prototype chip was attached to the International Space Station with a mass of 10 grams [6].

As for the near future, it is possible that we will not use only point-to-point protocols for transferring the data to Earth. Takashi Iidaa et al discussed the cost of the global ring satellite system [7]. They also examined the user terminal which shares an earth terminal by many users through a wireless local area network. According to their work, the global ring satellite has a possibility of a good cost-competitive system because the communication system can be configured only by satellite system without a terrestrial network.

However, there may be situations in which it is impossible or not desirable to construct a fix infrastructure for the communication, so it is worth to examine how we can use the ad hoc networks in space communication and space exploration. Duboisa et al. [8] evaluated the exploration of the Solar System by ad hoc wireless sensor networks and collected the requirements for this kind of sensor networks. According to their work, the topology of the network (i.e. number of nodes, distance between the nodes, etc.) will largely depend on the type of the mission. The sensing nodes have to face different constraint depending on the exploration mission objectives. The nodes deployment technique can have a strong impact on the network. Sensing nodes can be either fixed on the ground of a planet or move relative to each other.

There are routing approaches that attempt to improve the performance of a sparse network when its dynamics are known in advance like the Low Earth Orbiting (LEO) satellites based networks. Jain et al described the most important metrics of interest [9] which are the contact times between nodes (their starting times and durations), queue lengths of the nodes, and the network traffic load. If the routing protocol knows these metrics, it can select the optimal routes between the nodes. Despite that the implementation of the complete knowledge in a distributed environment is a very hard task, its evaluation is important as it constitutes the best case scenario compared to other cases where only a partial knowledge is available to the routing protocol.

The next two approaches were developed for Earth-environment. However, both of them could be used in communication on a distant planet. As for the controlled-contact based routing, Jain et al in [9] have introduced architecture for a sparse network constituted by fixed sensors and extended by mobile nodes called MULEs (Mobile Ubiquitous LAN Extensions). MULE's task is to collect data from sensors, buffer it and drop it off later to a set of fixed base stations representing data sinks. Their basic observation confirms that an increase in the MULE density will improve system performance and leverage resource consumptions [10].

We developed an information dissemination protocol called IOBIO for a special self-organizing network where the network consists of a huge number of disconnected nodes with low power. These nodes are highly mobile, while any attempt to centralize management and coordination is impossible [11]. It uses a simple 3-stage handshake to discover neighbors that are interested in one of the carried messages. The goal of the protocol is to reduce the unnecessary load of neighboring nodes by duplicated or unnecessary data.

3 Information dissemination on a Solar System body's surface

In this section, we focus on a possible communication network on a surface of a Solar System body like Moon, a distant planet or an asteroid. The aim of the established network is to collect scientific data (typical measured information, like speed of wind, actual compound of the atmosphere, humidity of atmosphere, humidity of soil, compound of soil, seismic measurements, data on the surface nature etc.) and to forward these data to Earth-based station.

3.1 Requirements

The two main requirements are the energy efficiency and robustness. The energy efficiency means we have limited battery resources for the communication. However, the units can and will recharge themselves using solar panels. Configurations and algorithms are necessary to charge to battery with a minimum energy-need. The robustness is crucial, because we have to handle the disappearing units from the network. This can happen because of the damage on the equipment caused by the environment or a system failure. The communication link can break due to weather conditions as well (like storms). Although in an Earth-environment it is simple to repair or change the damaged unit, we cannot do it on the surface of a Solar System body. To be more exact, we can do it, but only with a high-cost man-controlled mission. There are many other requirements for a communication network, but these two are the most important for a successful scientific space mission.

3.2 Elements of the communication network

The network's configuration and parameters depend on the scientific goals of the space mission. The possible elements are measuring equipments (sensors), mobile units (rovers or air planes) and at least one orbiting communication satellite.

The sensors are forming an ad hoc network on the surface of planet. On the contrary to the sensor elements of an ad hoc network on Earth, these are placed without any human interaction. The sensors can be released in the atmosphere and fall down or settled down by a moving rover. These two different methods require different information dissemination techniques, since in the second case we can plan the exact places of the sensors. In this article we focus on the first case, when the sensors are 'dropped' into the surface. In this case, if the sensors are prepared for different measurements, they can start their scientific measurement right in the atmosphere, then continue it with measurements on the ground. However, this will increase the cost of a sensor. The sensors are very cheap units and thousands of them have to be used to achieve the scientific goal of the space mission. They have a built-in battery and a little solar panel allowing recharging their batteries. The scientific measurement should be simple so that it can be conducted with limited energy. Each sensor has its own identification number (id), and the measured information is tagged with the sensor's id and the local time of measurement.

The rovers and air planes are mobile units, which can collect the measured information from the sensors. However, they could have their own scientific missions as well, doing measurements with their equipments. To achieve a cost-effective network, they should be cheap. If they are moving directly on the surface, we are talking about rovers. In case they are not moving on the surface but flying over it, we are talking about air planes. The automatic robotic air planes can collect data from the sensors located directly on the surface. Both the rovers and the autonomous powered airplanes can use built-in battery and solar-panels to satisfy their energy-requisite.

The satellite is orbiting around the planet, and it is responsible for receiving measured data from the network on the planet and forwards them to Earth. The satellite can be a "simple" communication satellite which only relays the data to Earth. However, because of the cost of the space mission, it is recommended to use a "complex" satellite which has not only a communication function but an own scientific mission as well, like remote sensing.

3.3 Possible configuration of the network

The exact possible configuration depends on the aim of the scientific mission. However, we can distinguish three different types. The difference between the configurations is based on the necessity of the mobile units. We plan to build up a cost-efficient communication network which is based on cheap units, and the expensive mobile units can increase the total cost of the mission. But the main cost of such a communication network has to be taken into account which is related to the transfer of the necessary elements between the Earth and the chosen Solar System body.

3.3.1 Network without mobile units

In this configuration there are no mobile units. If there is a limited amount of sensors, then they can communicate with each-other, and there is no need to collect information and transferring devices. The information is forwarded between the measuring units. To achieve an energy efficient network only selected units will communicate with the orbiting satellite, and the information will automatically be forwarded to these units. To prevent a communication overhead caused by the failure of the satellite-contact nodes, all of the sensors are physically able to contact the satellite, and the satellite communicating units are selected randomly. The overview of such a network is illustrated in Fig. 2.

In this configuration the sensors need to store measuring information of other nodes in their memories and to transfer the measured data to the satellite. Both of these requirements increase the cost of the measuring units.

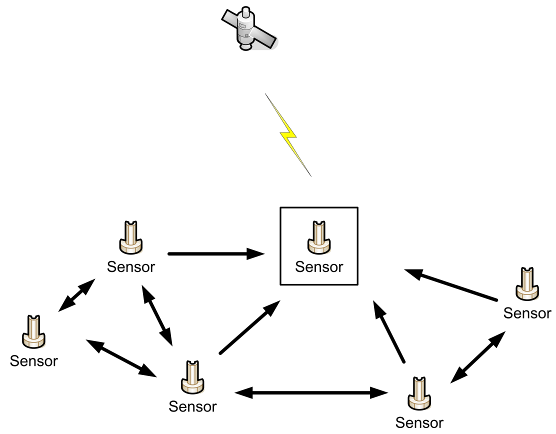

Fig. 2. Overview of the network based only sensors. The marked item is the sensor unit which marked itself as a satellite-contact unit for a given time period.

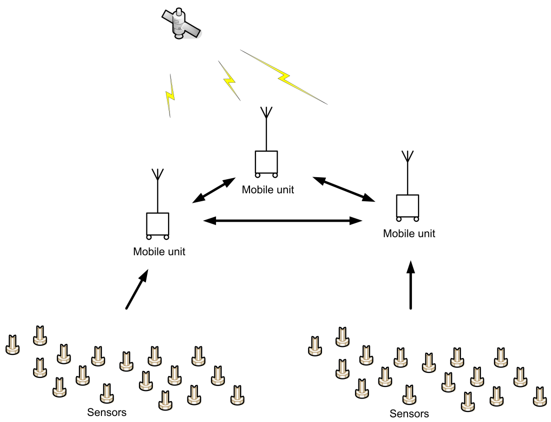

Fig. 3. Overview of the network in case of the second configuration. The mobile units collect the information from sensors, share it with each other, and transfer it to the orbiting satellite.

3.3.2 Network with full-working mobile units

We do not need complex sensors with satellite connections if we have mobile units which are responsible to collect the measured information from the sensors. The sensors are working on their scientific measurement, and the measured data are transferred to mobile units. The sensors do not communicate with each other, they forward their measurement data only to the mobile units. In this configuration more sensors are used than in the previous configuration (more than 10 000 sensors), and mobile units are needed as well. The average number of mobile units around the specified area is between 100 and 3000.

To help the scientific mission, the mobile units can carry out measurements as well. In this configuration all of the units are able to communicate with the satellite. However, they have to share their collected data to satisfy the requirement of robustness. The overview of such a network is illustrated in Fig.3.

This configuration is easy to establish. However, there could be starving units which cannot transfer their data to the satellite because they find the channel busy during the possible interval of the satellite communication. Since the information is distributed among the mobile units, there is only a little chance that the measured data are not transferred to the satellite because of the starving unit.

3.3.3 Network with limited satellite-contact mobile units

The arrangement of this configuration is similar to the previous communication, but only selected mobile units can communicate with the orbiting satellite. To prevent a communication overhead caused by the failure of the satellite-contact nodes, all of the moving units are physically able to contact the satellite, and satellite communicating node is selected randomly. The overview of such a network is illustrated in Fig. 4.

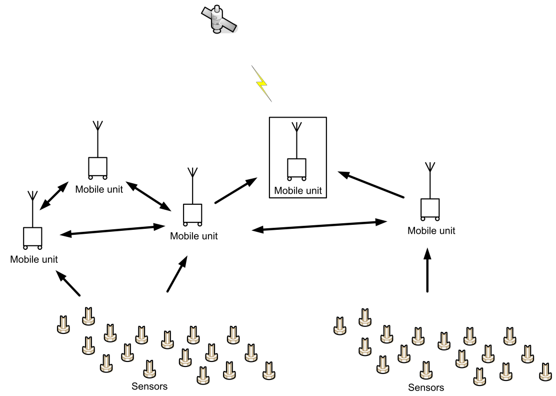

Fig. 4. Overview of the network when only limited numbers of mobile units are able to transfer the measured data to the satellite.

This configuration handles the problem of starving units and satisfies the requirement of robustness and energy efficiency as well.

4 SPIO, the Space Adapted IOBIO

In the previous section we introduced different configurations for a communication network established on the surface of a distant Solar System body like Moon, Mars or an asteroid. Now we would like to introduce an information dissemination algorithm, which can work in these configurations. In this article we introduce its properties for Configuration #C.

4.1 Overview of SPIO

The SPIO (SPace adapted IObio) is the space-environment modified version of our IOBIO protocol. Here the whole protocol is introduced. The original IOBIO was described by Simon et al [11]. The strength of the SPIO algorithm is that no measured data is sent when it is unnecessary. It is based on a 2-stage process between the sensors and mobile units and a 3-stage handshake process between mobile units which can help to enhance power saving.

The main elements of SPIO are sensors and mobile units. The sensors are measuring devices which are cheap and could be easily placed without any human interaction. The mobile nodes move on the surface or fly over the surface and collect the information from sensors and disseminate it in the ad hoc network formed by the mobile units. The mobile units have used random walk as a mobility model so far, however, for future work a graph-based walking should be considered.

4.2 General description of SPIO

The protocol is developed for Configuration #C which was described in Subsection 3.3.3. The detailed description of this configuration is the following:

Step 1. The sensors are taking measurements and forwarding their measured data to mobile units using an information dissemination protocol like.

Step 2. The mobile units receive the data from sensors, and distribute the data among each other.

Step 3. When a node (Unit A) receives a strong broadcast signal of the orbiting satellite, it starts a timer T for a random time interval, and goes to a waiting state.

Step 4/a. If timer T is over, Unit A decides to be a satellite-contact unit with given probability p. If A marks itself as a satellite-contact node, it chooses a random number and advertises this role to its environment (with the same method as in Configuration #A).

Step 4/b. If timer T is running when Unit A receives a satellite-contact message from another unit which marked itself as a satellite-contact unit, Unit A stops the timer and advertises its neighborhood that it knows a satellite-contact unit with same method as in Configuration #A.

Step 4/c. If timer T is not running, and Unit A receives a satellite-contact message, it drops the message.

Step 5. The measured data is distributed among the mobile nodes. However, Unit A does not forward any data to other nodes if it marked itself as a satellite-contact node.

Step 6. When Unit A receives a strong broadcast signal of the orbiting satellite, and Unit A was a satellite-contact node, it transfers the collected measured data to the satellite with a point-to-point protocol. After the successful transfer it chooses a random number, and the process starts from Step 1.

4.3 Messages of SPIO

There are three different communication scenarios in SPIO. The first one is the sensor - mobile unit communications, the second one is the advertisement of satellite-contact node and the third one is the mobile unit - mobile unit communication.

4.3.1 Sensor - mobile unit communication

Between sensors and mobile units SPIO, a 2-stage protocol is used. The first step is a short request sensor data message (REQ_SD), which is periodically sent by the mobile units and contains the ID of the mobile unit. When a sensor receives a REQ_SD message, it broadcasts its measured data and clears its memory.

The detailed steps of the protocol are the following.

1 The sensor A takes a measurement, and will have one or more measured data.

2 The mobile unit B arrives. It broadcast its arrival with the a request message (REQ_SD)

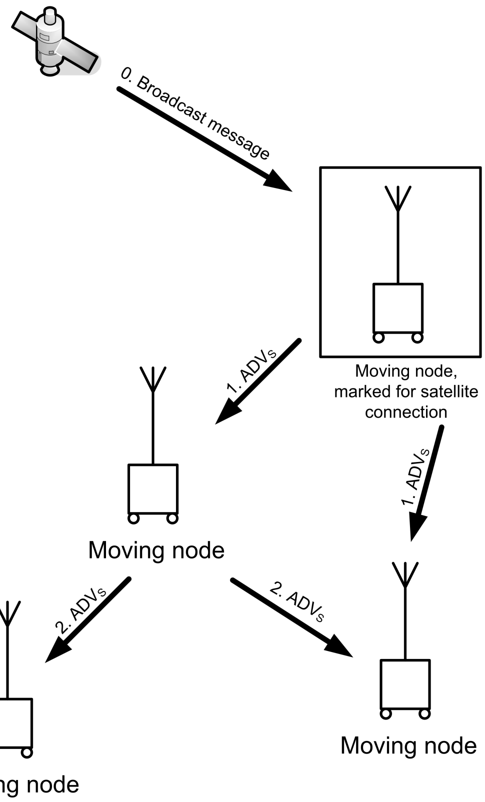

Fig. 5. Messages of SPIO, focusing on the satellite-contact-marking advertisement process

3 Sensor A receives the request message, and sends its measured data to the mobile unit B (DATA_SD).

4.3.2 Satellite communication marking

When a node marked itself as a satellite-contact node, it has to advertise this fact to its neighbors to avoid the collision during the satellite transmission. For this it uses an advertisement message (ADV_S), which contains its identification number (ID) and a random number. With the help of this number the nodes can distinguish the different satellite-marking advertisement from the same unit. A sample is illustrated in Fig.5.

The detailed steps of the protocol are the following.

1 The mobile unit A marks itself as a satellite-contact node.

2 A advertises this fact with a special advertisement message (ADV_S), which contains its identification number (ID) and a random selected number. When A starts to broadcast the ADV_S message, it starts a T2 timer as well. When T2 is over, it stops broadcasting ADV_S.

3 The mobile unit B receives the ADS_S message.

4 If T is a timer, started when B received a broadcast signal from the orbiting satellite, is still running, it stops its timer, broadcasts the ADS_S message and starts a T2 timer. If T2 is over, it stops broadcasting ADV_S.

5 If T timer is not running, B drops the received ADS_S message.

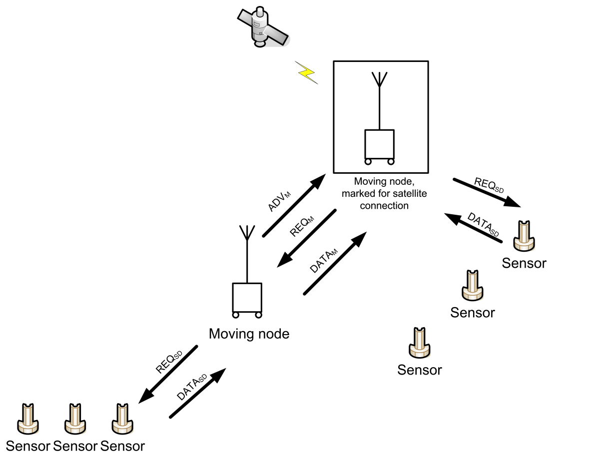

Fig. 6. Messages of the SPIO, focusing on the communication between mobile units.

4.3.3 Mobile unit - mobile unit communication

Between mobile units SPIO uses a 3-stage handshake protocol. This protocol allows to avaoid broadcasting in the communication network every time. The first and second steps use short control messages; the broadcasting of the data only happens in the third step, and only when it is needed. The overhead is decreased, because the broadcasting of the message happens only upon a request nearby. This protocol uses three message types. The advertisement messages (ADV_M) are sent periodically, and they contain the list of measured data that the sending unit has. If the units in the neighborhood are interested in the advertised message, they send a request packet (REQ_M). In the response the mobile unit sends the required DATA packets. The transmission of ADV_M and REQ_M is done after a random selected delay. During this delay the mobile units listen to each other, and they send a request message for packets that were not requested so far.

We assume that a lot of mobile nodes are in their transmission range. In this case a lot of advertisement and request messages are sent, and the networks will work as a simple broadcast-network. The mobile units send only short advertisement messages and the data will be sent only if a unit needs it. A sample is illustrated in Fig.6.

4.4 Energy consumption

We studied the energy consumption of the network which uses SPIO protocol in different scenarios. In a simple case the energy consumption of packet trasmission can be described as

$$\text{Energy} = m \cdot \text{size} + \text{b} \tag{1}$$

where $m \cdot$ size is the incremental component which depends on the size of the packet, b is a fixed component associated with the device state changes and channel acquisition overhead [12]. We took into further parameters including the number of sensors (N_S), number of mobile units (N_{MU}), number of satellite-contact mobile units (N_{SCU}), average time interval between measurements (T_M), and average time interval between satellite - mobile unit contacts (T_S). All of these values are related to scientific measurement which depends on the aim of the space mission. Other interesting parameters are related to the message transfer. We defined the cost of messages based on the number of bits needed to be transferred during the communication. However, we take into account that the mobile unit - mobile unit communication needs more energy than the sensor - mobile unit and the satellite communication needs even more.

Energy consumption in case of a Point-to-point Protocol (PPP) (every sensor has direct communication with the satellite)

$$E_{PPP} = N_S \cdot \delta_S \cdot (m_{SSat} \cdot \text{size}_{SSat} + b_{SSat}) \tag{2}$$

where N_S is the number of the sensors, δ_S is the average number of satellite-sensor contacts is a PPP protocol per time unit, size_{SSat} is the size of the data message, m_{SSat}, b_{SSat} are components for the energy calculations.

As for the energy consumption for the whole network, in case of the SPIO protocol we have three different components.

The first component is for collecting the measured information from sensors,

$$E_{Part\_1} = N_S \cdot \delta_{MS} \left(m_{M2S} \cdot \text{size}_{\text{REQ\_M2S}} + b_{M2S}\right) + \left(m_{M2S} \cdot \text{size}_{\text{DATA\_M2S}} + b_{M2S}\right) \tag{3}$$

where the first part represents the energy need for the request message, the second one for the data message. The second component is for transferring the data among the mobile units,

$$E_{Part\_2} = N_{MA} \cdot \delta_{MM} \cdot [(m_{M2M} \cdot \text{size}_{\text{ADV\_M2M}} + b_{M2M}) + (m_{M2M} \cdot \text{size}_{\text{REQ\_M2M}} + b_{M2M}) + (m_{M2M} \cdot \text{size}_{\text{DATA\_M2M}} + b_{M2M})] \tag{4}$$

where the parts represent the advertisement, request and data messages respectively.

The third component is for transferring the data from the selected mobile units to the satellite,

$$E_{Part\_3} = N_{SM} \delta_{Sat} \cdot (m_{Sat} \cdot \text{size}_{Sat} + b_{Sat}) \tag{5}$$

where δ_{Sat} is the average number of satellite-mobil contacts per time unit. The different components are applied for different type of communication devices e.g. sensors, mobile units and satellite-contact units.

We used random walk mobility model for simulating the movement of the mobile units. A few simulation results are illustrated in Fig.7.

We can conclude that the simple point-to-point protocol had better performance in an environment with few units. The SPIO had better results than a point-to-point or simple broadcast protocol when thousands of sensors and mobile units exist in the network, if the size of the advertisement and request messages is significantly less than the size of the data message. The solution is that only selected mobile units contact the satellite instead of all nodes, which reduces the energy-need of the total network as well.

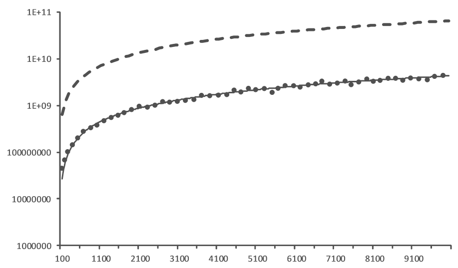

Fig. 7. Comparing the SPIO protocol to PPP. The dashed line represents the energy need in case of PPP, the pointed line represents it in case of SPIO. Horizontally the number of sensors, vertically the total energy need for information dissemination in the whole network is illustrated.

5 Conclusion

If we build up a network from a lot of cheap measuring devices which were settled down on the surface of a planet, then the energy efficiency and robustness will be the two main parameters since the manual charging or repairing of the devices are not possible. Adapting to the changing environment it is a tool for working in an automatic environment without human central control on the surface of a distant planet. The information dissemination solutions should meet the high requirements of energy efficiency. In this article we showed different configuration to deal with the message forwarding problem and introduced an information dissemination protocol for space environment.

As for future work, it will be useful to construct a robust communication system on the surface of a distant planet where the devices could adapt to the changing environment and could select among different types of information dissemination algorithms without having any information of their global environment.

References

1 **Pellegrini F, Miorandi D, Linner D, Bacsárdi L, Moiso C**, *BIONETS Architecture: from Networks to SerWorks*, Proc. Workshop on Technologies for Situated and Autonomic Communications, 10-12 Dec 2007, DOI 10.4108/ICST.BIONETICS2007.2429.

2 **Simon V, Bacsárdi L, Szabó S, Miorandi D**, *BIONETS: a new vision of opportunistic networks*, Proc: Wireless Rural and Emergency Communications Conference (February 01).

3 **Bacsárdi L, Bérces, Varga E, Csvórics T, Simon V, Szabó S**, *Strategies for Reducing Information Dissemination Overhead in Disconnected Networks*, The 16th IST Mobile and Wireless Communications Summit, 01-05 Jul 2007, DOI 10.1109/ISTMWC.2007.4299236.

4 **Furniss T**, *A History of Space Exploration*, Mercury Books, 2006.

5 **Dudás L, Varga L, Seller R**, *The communication subsystem of Masat-1, the first Hungarian satellite*, Proc. SPIE 7502, posted on 2009, DOI 10.1117/12.837484, (to appear in print).

6 **Atchison J A, Peck M**, *Length Scaling in Spacecraft Dynamics*, Journal of Guidance Control and Dynamics **34** (2011), no. 1, 231-246, DOI 10.2514/1.49383.

7 **Iidaa T, Suzukia Y, Arimotoa Y, Akaishib A**, *Global ring satellite communications system for future broadband network*, Acta Astronautica **56** (April, 2005), no. 7, 688-695, DOI 10.1016/j.actaastro.2004.11.001.

8 **Duboisa P, Botteronb C, Mitev cC, Menond C, Farineb P, Dainesie P, Ionescue A, Sheaa H**, *Ad-hoc wireless sensor networks for exploration of Solar-system bodies*, Acta Astronautica **64** (April 2009 March), no. 5-6, 626-643, DOI 10.1016/j.actaastro.2008.11.012.

9 **Al Hanbali A, Ibrahim M, Simon V, Varga E, Carreras I**, *A Survey of Message Diffusion Protocols in Mobile Ad Hoc Networks*, Proc: Inter-Perf 2008, 2008, DOI 10.4108/ICST.VALUETOOLS2008.4510.

10 **Puccinelli D, Haenggi M**, *Wireless sensor networks: applications and challenges of ubiquitous sensing*, IEEE Circuits and Systems Magazine **5** (2005), no. 3, 19-31, DOI 10.1109/MCAS.2005.1507522.

11 **Simon V, Bacsárdi L, Bérces M, Varga E, Csvórics T, Szabó S, Imre S**, *Overhead Reducing Information Dissemination Strategies for Opportunistic Communications*, Proc: IFIP/IEEE MWCN 2007, posted on Unknown Month 19, 171-175, DOI 10.1109/ICMWCN.2007.4668203 , (to appear in print).

12 **Feeney L, Nilsson M**, *Investigating the energy consumption of a wireless network interface in an ad hoc networking environment*, INFOCOM 2001, 2001, pp. 1548-1557, DOI 10.1109/INFCOM.2001.916651.