

**A NEW SPGR BASED ENERGY-EFFICIENT ROUTING TECHNIQUE
FOR AD-HOC NETWORKS**

M.Sc. THESIS

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Department of Computer Engineering

Computer Engineering Programme

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**TASARSIZ MOBİL AĞLAR İÇİN SPGR TEMELLİ
ENERJİ VERİMLİ YENİ BİR YÖNLENDİRME TEKNİĞİ**

YÜKSEK LİSANS TEZİ

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MAYIS 2015

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.....

Date of Submission : **4 May 2015**
Date of Defense : **27 May 2015**

To my family,

FOREWORD

During my study for master degree of science in Istanbul Technical University I have worked on wireless sensor networks. I would like to express my sincere gratitude to my supervisor, Prof. Dr. Sema Oktug. I very appreciate the time and attention she had spent during my master study and our research for this thesis.

I also appreciate my family, who was always with me, for their patience, help and support. Especially, I would like to say thank you to my sister, for her support and inspiration for going ahead in my life.

May 2015

Fidan GARAYLI
Computer Engineer

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ABBREVIATIONS

WSN	: Wireless Sensor Networks
GPS	: Global Positioning System
MANET	: Mobile Ad Hoc Network
VANET	: Vehicular Ad Hoc Network
RWM	: Random Waypoint Mobility
OPNET	: Optimized Network Engineering Tool

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A NEW SPGR BASED ENERGY-EFFICIENT ROUTING TECHNIQUE FOR AD-HOC NETWORKS

SUMMARY

Wireless Sensor Networks is a group of a spatially dispersed and densely deployed sensors. When the sensor nodes of WSN become mobile and the network does not have the stable infrastructure, it becomes an ad hoc network. Ad hoc networks have become more popular nowadays, especially for people who always use laptops and other portable devices. Wireless networks enable us to have access to the internet regardless of where we are. With the development of mobile equipment, such as mobile phones and laptops, we want to have an uninterrupted service while using wireless networks, even when we are moving from one area to another. It is more convenient compared to the wired Ethernet or other network access. In this respect battery lifetime of these type equipments and energy-efficiency of ad hoc networks have been a crucial issue in recent years.

In his work we have presented an energy-efficient geographic routing technique based on the shortest path based routing method. Firstly, geographic forwarding was studied in terms of energy-efficiency. The distinctive feature of the geographic forwarding is the ability to be aware of the geographic location of nodes. Using location information, the nodes can develop more reliable packet forwarding function. Then, a new energy-efficient geographic routing technique is introduced.

According to the proposed technique the source and the destination are linked with a virtual Euclidean line. During the selection process of the next forwarder node among the neighbors, the node tries to choose the one which is nearest to the Euclidean line and also to the destination node. Selection method is the function of the distance between the neighbor and the sink; and the distance between the neighbor and the virtual Euclidean line. In other words, the node selects the neighbor, which the minimal distance to the sink and Euclidean line, this approach guarantees the delivering of the packets along the shortest path. Additionally, proposed technique takes into consideration battery lifetime of the network node. Selection function includes the energy level parameter of the neighbor nodes: the forwarder node sends the packet to the neighbor, which is not only in the shortest path to the sink, but also has a maximum energy level. Therefore, the closest neighbor selection function introduced combines the two parameters: distance and energy level. The method can be rearranged according using the weighted value according to the demands of the network.

The offered technique also uses the backtracking method. If the current forwarder node cannot find the next one among its neighbors, which is in shortest path in a comparison with itself, it re-forwards the packet to the previous node.

The technique was simulated on OPNET tool. We have used three scenarios which differs in mobility type. In the first scenario we have tested the technique employing

absolutely static network. The second scenario is partially mobile: half of the network nodes are mobile, the rest is static. The third scenario is absolutely dynamic scenario, where all the nodes of the network are mobile.

All scenarios were tested under the exponential and the Pareto traffic with the different parameters. We have compared the proposed technique with Geographic Routing Protocol (GRP) and Shortest Path Based Geographic Routing (SPGR), on which our method is based. In a development of the these techniques energy parameter of the network nodes was not taken into the consideration. All the techniques were compared in terms of the delay, average number of the received data packets. In order to analyze the energy consuming parameter of the methods mentioned above, we have integrated energy parameter to the GRP and SPGR.

It is shown that the technique introduced has low delay and a large number of received packets compared to the GRP technique and SPGR technique. Also Average Number of Received Data packets are also considerable higher in our technique.

To sum up, we have studied the geographic routing based techniques for ad hoc networks. Using the main idea of SPGR forwarding, we have integrated the energy-efficiency parameter and developed the neighbor selection function. The node chooses the neighbor with the maximum energy level and with the shortest distance to the sink considering the virtual line between the source and the sink.

In the future work, we are planning to improve the performance of the Angular Routing Protocol. The integration of energy parameter will be studied extensively. Furthermore, the possible modification of the protocol to improve its performance results will also be considered. Multi-source transmissions will be considered as a future work.

TASARSIZ MOBİL AĞLAR İÇİN SPGR TEMELLİ ENERJİ VERİMLİ YENİ BİR YÖNLENDİRME TEKNİĞİ

ÖZET

Kablosuz Sensör Ağlar belirli alanda yoğun olarak dağılmış sensörler topluluğudur. Kablosuz sensör ağlarda bulunan sensörler mobil olduğunda ve bulundukları ağların belirli sabit altyapısı olmadığında tasarsız sensör ağlara dönüşürler. Günümüzde, dizüstü bilgisayarlar ve diğer taşınabilir cihazlar sıklıkla kullanıldığından tasarsız mobil ağlar son derece yaygınlaştı. Kablosuz Sensör Ağlar konuma bağımlı olmadan internet erişimi sağlamaktadırlar. Mobil cihaz ve bilgisayarların yaygınlaşmasıyla kablosuz sensör ağları kullanılırken bir konumdan diğer konuma geçildiğinde dahi kesintisiz internet servis ihtiyacı doğmuştur. Böylece ethernet ve diğer kablolu internet erişim servisleri ile kıyasla kablosuz sensör ağların kullanışlılığı daha da belirginleşmiştir. Bundan dolayı donanım sistemlerinin pil ömrü ve tasarsız mobil ağların enerji verimliliği konusu son yıllarda daha da önem kazanmıştır.

Bu çalışmada en kısa yol ile aktarma üzerine kurulmuş enerji verimli coğrafi yönlendirme yöntemi sunulmuştur. Öncelikle, coğrafi yönlendirme teknikleri enerji verimliliği açısından araştırılmıştır. Coğrafi yönlendirmenin en önemli özelliği ağ düğümlerinin konumlarının belirli olmasıdır. Düğümlerin coğrafi konumları kullanılarak daha güvenilir paket aktarımı sağlanmaktadır.

Önerilen tekniğe göre, kaynak ve varış yeri hayali Öklid çizgisi ile bağlanmaktadır. Komşu düğümler arasında bir sonraki gönderilecek düğüm seçilirken iki nokta arasındaki en kısa yolla paket gönderimi, en az gecikme ve yüksek performans göz önünde bulundurularak yapılır. Ama yoğun paket aktarımı söz konusu olan ağlar için bu tarz aktarım tekniği paket tıkanıklığına ve uzun paket aktarma sırasına neden olmaktadır. Özellikle, kesintisiz elektrik kaynağının bulunmadığı tasarsız ağlar için en kısa yol üzerinde bulunan düğümlerin enerji düzeyi çok hızlı şekilde azalmaktadır. Paketlerin doğrudan en kısa yol üzerinden değil, kaynak-varış noktaları arasındaki hayali Öklid çizgisine yakın tutmakla gönderimi en kısa güzergâha yakın düğümlerin kullanılmasına izin vermektedir.

Sunulan teknikte komşu düğümler arasında bir sonraki paket gönderici düğümün seçim zamanı, düğüm hayali Öklid çizgisine ve varış noktasına en yakın olan düğümü seçmektedir. Seçim yöntemi parametresi komşu düğümle varış noktası ve Öklid çizgisiyle komşu düğüm arasındaki mesafenin fonksiyonu olarak belirlenmektedir, yani varış noktasına ve Öklid çizgisine en yakın olan komşu düğüm seçilmektedir.

Bunun yanı sıra, önerilen teknik ağdaki düğümlerin pil ömrünü de dikkate alınmaktadır. Bu teknik için dengeli enerji tüketimini sağlayan enerji parametresi kullanılarak, bütün ağa enerji verimliliğini kazandırılmıştır. Gönderici düğüm kendi komşu düğümleri arasında enerji düzeyi en fazla olan paket aktarımını sağlamaktadır.

Bu çalışmada kullanılan enerji modeli her bir düğüm paket aktarım sürecine aynı enerji düzeyi ile başlar ve paket aktarımı veya paketin kabul edilme zamanı belirli düzeyde enerji harcar. Düğümlerin bekleme sırasında da belirli düzeyde enerji tüketimi devam eder; bekleme sürecinde uyku moduna geçerek enerji tasarrufunun sağlanması bu çalışmada dikkate alınmamıştır. Önceden belirlenen enerji düzeyi limitinden daha az enerjisi kalan düğümler paket aktarımında kullanılamaz, bu düğümlerin paket kabul etmesi veya paket aktarması durdurulmaktadır. Komşu düğüm seçim fonksiyonunda enerji düzeyinin dikkate alınması en kısa yol üzerinden enerji tüketimini dengede tutmayı sağlamaktadır.

Böylece, seçim fonksiyonu komşu düğümlerin enerji düzeyleri parametresini de dahil etmektedir. Gönderici düğüm sadece varış noktası istikametinde en kısa yol üzerinde bulunan komşu düğümü değil, aynı zamanda enerji düzeyi en fazla olan komşu düğümü seçmeye çalışmaktadır. Bu nedenle, en yakın komşu düğümü seçme fonksiyonu mesafe ve enerji düzeyi parametrelerini kapsamaktadır. Bulunan ağın gereksinimlerine göre bu parametrelerin ağırlık katsayıları değiştirilerek fonksiyon yeniden düzenlenebilir. Enerji tasarrufu ön planda olan ağlar için enerji düzey parametresinin ağırlık katsayısı artırılarak, ya da paket aktarım zamanı ön planda olan ağlar için mesafe parametresinin ağırlık katsayısı artırılarak seçim fonksiyonu kontrol edilebilir.

Ağdaki bütün düğümlerin konumu GPS yöntemiyle belirlenir. Ağda paket aktarımı başlamadan bütün düğümlerin ilk konumunu belirlemek için sel basma yöntemi kullanılır. Düğümlerin ilk konumlarını içeren paketler ağdaki bütün erişilebilir düğümlere dağıtılır. Paket aktarımı başladıktan sonra düğümler komşu düğüm tablolarındaki konum güncellemelerini "hello" paketleri aracılığıyla gerçekleştirir. Bu paketlerin gönderilme sıklığı ağın mobilliğine bağlı olarak değişir; düğümler belirli mesafe kat ettikten ve belirlenmiş zaman aşımından sonra etraftaki düğümlere konum bilgilerini içeren paket aktarımı yapar. Böylece, komşu düğüm tabloları güncellenir.

Bu çalışmada sunulan teknik yeniden gönderim yöntemini de kullanmaktadır. Geçerli düğüm kendi komşu düğümleri arasından varış noktası yönünde yerleşen bir düğüm bulamadığında, paket bir önceki gönderici düğüme geri aktarılır.

Önerilen çalışma OPNET ağ simülasyonu aracılığıyla test edilmiştir. Simulasyonlarda mobil hızına göre değişkenlik gösteren üç farklı senaryo kurulmuştur. Birinci senaryoda, yöntem tamamen statik ağda test edilmiştir. İkinci senaryo kısmen mobil özelliğini taşımakta olup, ağ düğümlerinin yarısı mobil, geri kalanı statik olarak belirlenmiştir. Üçüncü senaryoda tamamen dinamik bir ortam olarak tasarlanmıştır.

Yukarıda belirtilen bütün senaryolarda simulasyon ortamında üstel ve Pareto trafik oluşturulmuştur. Bu yöntem Coğrafi Yönlendirme Protokolü (GRP) ve En Kısa Yola dayalı Coğrafi Yönlendirme (SPGR) metotları ile karşılaştırılmıştır. Çalışmada sunulan yöntem SPGR üzerine kurulmuştur. Karşılaştırılan her iki yöntem coğrafi yönlendirme bazlı olsa da, ağdaki düğümlerin enerji düzeyi dikkate alınmamıştır. Her üç yöntem paket aktarım gecikmesi, başarıyla gönderilen data paketlerin ortalama oranı ve ağın genel yaşam süresi açısından kıyaslanmıştır. Enerji tüketim oranlarının ve ağın yaşam süresinin karşılaştırılabilmesi için GRP ve SPGR tekniklerine enerji tüketim parametresi entegre edilmiştir.

Sunulan teknik karşılaştırdığımız yöntemlerle kıyaslandığında daha az paket aktarım gecikmesi ve daha uzun ağ yaşam süresini sağladığı görülmüştür. Ayrıca, başarıyla gönderilen data paketlerin ortalama oranı da sunulan çalışmada daha yüksek olarak belirlenmiştir.

Özetle, çalışmada tasarsız mobil ağlardaki yönlendirme teknikleri, özellikle de coğrafi bazlı yönlendirme teknikleri araştırılmıştır. SPGR yönlendirmeye dayalı komşu düğüm seçme fonksiyonu enerji verimlik parametresi entegre edilmekle geliştirilmiştir. Gönderici düğüm, varış noktasına ve hayali çizgiye en yakın ve enerji düzeyi diğerlerinden daha yüksek olan komşu düğüme paket aktarımı sağlayacaktır.

1. INTRODUCTION

Wireless Sensor Networks are composed of a large number of autonomous and densely deployed sensor nodes. Each sensor node has its portable power supply, radio transceiver. When the establishment of a stable network infrastructure is not possible or not feasible or topology change occurs very frequently, ad hoc infrastructure based networks becomes more preferable than the others. When these nodes or sensors also have the ability to move, the network is called MANET (Mobile Ad Hoc Network). Nowadays, due to the increase in the number of portable devices MANETs are becoming very popular. Using wireless connections, they can communicate with the other nodes from any place and any time without using a fixed network infrastructure and any centralized management system.

1.1 Problem Definition

The main and general problem of portable devices or sensors is their battery lifetime since the power supply of each node is limited. Each sensor node is a source node, but all of them are also responsible to forward (relay) the received packets according to their destinations. Routing of packets in a network is implemented according to network protocols. Therefore, developing the energy-efficient network protocol for MANET systems becomes very critical. The protocol should provide not only high throughput, low delay, but also longer network lifetime. Consequently, in order to provide optimal solutions considering the parameters above, the network protocols for MANETs are evolving continuously.

1.2 Purpose of Thesis

In this work, our target is to improve Shortest Path Based Geographical Routing Algorithm (SPGR) in WSNs based on energy efficiency concerns. In our work, we have added energy-constraint for the SPGR geographic routing algorithm: while the

node forwards a received packet to the neighbor node, it takes into account not only the distance between the neighbor, source and destination nodes, but also their energy levels.

1.3 Author Contribution

Our contributions can be listed as below,

- The distance parameter for the neighbor selection method in the geographic routing was updated.
- Energy parameter was included to the selection method.
- During selection process of the next forwarder node the one with the highest energy level is chosen.
- Energy balance among the sensor nodes is focused.
- Statistics were obtained in the static, partially mobile and dynamic environment.
- The proposed technique is compared with the geographic based routing techniques, such as GRP and SPGR in terms of delay, throughput and network lifetime.

1.4 Structure of the Document

This thesis is arranged as follows: literature survey that includes survey of ad hoc routing protocols, its classification as flooding based, geographic based and hybrid protocols are given in the next chapter. Chapter 3 have introduced the new technique developed based on the shortest path based geographic routing protocol. Section 4 describes the simulation environment and simulation results of various metrics, such as delay, throughput and so on. Finally Chapter 5 concludes the thesis by giving future directions.

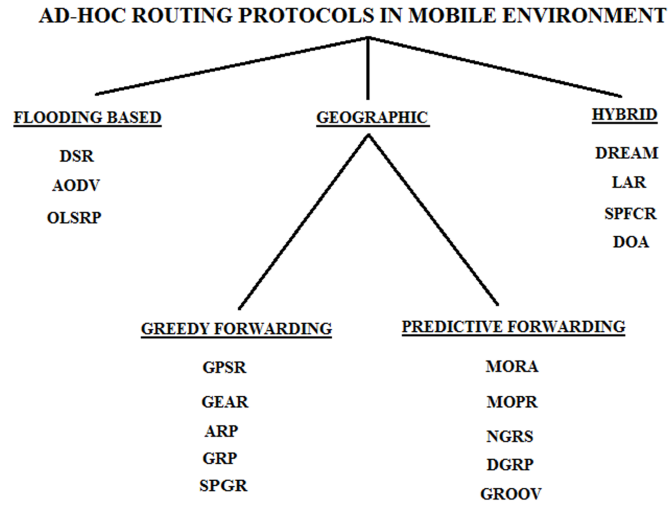


Figure 2.1: Classification of Ad hoc routing protocols in MANET.

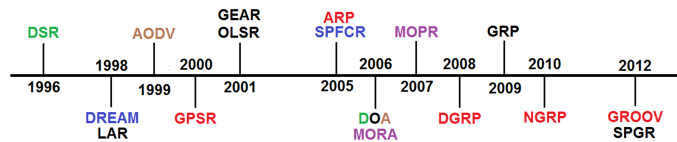


Figure 2.2: Timeline of Ad-hoc Network protocols in MANET

2. LITERATURE REVIEW

We can divide theoretical background of our work as follow: Flooding based, Geographic and Hybrid routing protocols. Geographical Forwarding is also can be considered as two sections: Greedy forwarding and Predictive Forwarding. The whole classification list and the timeline of appearing of the protocols which were studied are shown on the Figure 2.1 and Figure 2.2. On the Figure 2.2 the same color routing techniques shows the related ones.

2.1 Flooding Based Protocols in MANET

Ad hoc networks is a network with a free topology, lack of information about the infrastructure of the network is a challenge for creating routing tables. So, one of the methods of forwarding can be broadcasting of “special” packets to generate paths for sending the current packets.

One of the first works in this area is Dynamic Source Routing (DSR) [1] in Ad hoc Wireless Networks. The main technique of DSR is source routing. According to this approach sender node determines the whole path: all the forwarder nodes, each time when the source is going to send the packet to the sink node. The route discovery protocol is working as follow: route request- route reply- route record. Besides it, any time when the host gains new information about the route it can add new route information to its route cache. In other words, when the packet process newly arrived packet, it can also review the path along which the packet arrived or has to be sent, and as a result, adds the new entries in its route cache. Periodic routing advertisement messages were not used for this protocol, the new path is established only if there is a need for forwarding. Therefore, it reduces the network bandwidth and save the battery lifetime and as a result, network lifetime. All the nodes in DSR are working in promiscuous mode, which let them to obtain routing information even in the cases when the packet is transmitted by the neighbors, also route error messages can be spread over the network easily. But in the networks with radio transmission the communication links between two hosts can be not equally good in both directions, in that case, route error messages can be sent along another path. As a solution, the authors offer to send a route error packet also by source nodes towards the destination node, in order to send an error message along the previous path.

Ad Hoc on Demand Distance Vector Routing (AODV) [2] is also one of the classic routing techniques in ad hoc networks. The mechanism that was used for AODV is broadcast route discovery. Symmetric links were used between neighbor nodes. As in DSR, AODV also does not use any periodic routing table exchange messages; the node broadcasts hello messages only when there is a need for using it as a forwarder node. Source node begins path discovery process when it needs to establish a new path towards the destination node. Routing tables of intermediate nodes are the main information source for the forwarding of packets. For each node two type of counters

were used: a node sequence number and *broadcastid*. *broadcastid* counter controls the cases with multiple copies of the same broadcast messages. The sequence number counter is generated in order to determine if the route information is correct or not. RREQ packets are broadcast by the source node. Each node can act in two manners: it can send RREP packets to the source or also can broadcast RREQ packets of the source node. In the second case, the node keeps information about the neighbor node, which has sent the RREQ packet in order to establish the reverse-path route.

AODV and DSR protocols are also known as a reactive protocol, which means that the route between source and destination was established only when there was a request from the source node. Optimized Link State Routing Protocol (OLSR) [3] is based on link state algorithm. In contradistinction to AODV and DSR, OLSR is the proactive protocol: the route information towards all destination nodes are gained using control packets before the source request. Source can get information about the forwarder nodes along the path momentarily. However, unlike to the full flooding technique, each node sends the control packets not to the whole network, but to the selected neighbors, named multipoint relays. The Multipoint Relay set of each node is selected in such a way the control packets, which were sent by the node, can be achieved by the 2-hop distance neighbors. There must be a bidirectional connection between the node and Multipoint Relation set neighbors. The main purpose of such approach is reducing the number of control packet and eliminating of duplicate control packets sending. When the neighbor broadcasts the control packets only the neighbors, which are included in the Multipoint Relay set, can resend them, other neighbor nodes discard the packets.

2.2 Geographic Ad Hoc Routing

Geographic routing protocols are position-based protocols. Here, packets are sent from one point to another using their coordinates and network addresses. The location parameters of nodes are obtained by localization techniques, such as GPS and etc. Geographical forwarding can be considered under two groups: Greedy forwarding and predictive forwarding.

2.2.1 Greedy forwarding

The greedy forwarding geographical routing protocols mostly used in MANETs, while the predictive forwarding techniques are more applicable in VANETs (Vehicular Ad hoc Network). Both of these network types are ad hoc networks, without any stable network structure, but the main difference of VANET nodes is their high speed with respect to MANET nodes.

Greedy Perimeter Stateless Routing protocol (GPSR) [4] is a geographic routing protocol, based on two techniques: greedy forwarding and right-hand rule. Here, forwarder node can make decisions about the next forwarder neighbor according to the greedy mechanism. However, the problem of greedy forwarding technique is that a node can deliver the packet to the hole node: the forwarder one cannot send to the closer neighbor compared to itself. A solution of this problem is the use of right-hand rule. According to the right-hand rule when the packet arrives to the local maxima, the packet traverses along the edge in counter-clockwise direction.

The Geographical and Energy Aware Routing protocol (GEAR) [5] has an energy-efficient approach. It deals with static sensor nodes by dividing the area into regions. GEAR also has two steps of implementation: Firstly, the goal is to reach the target region of destination, i.e. the region where the destination node is located. Secondly, after the packet reaches the target region, the Recursive Geographic Forwarding technique or restricted flooding algorithm is used to reach the destination node.

Angular Routing Protocol (ARP) [6] is the modified version of the GPSR protocol. ARP also works in two stages. In the first stage, it uses a greedy routing technique similar to GPSR. Nevertheless, instead of perimeter mode (or right-hand rule) angle-based routing is used in the second stage. In order to avoid the local maxima problem of the greedy forwarding, forwarder node selects the neighbor with minimum angle. The advantage of using angle-based forwarding is the low-cost compared to the perimeter based one. Right-hand rule technique needs realization of the graph-planarization. This procedure is more expensive compared to the angle selection in ARP.

Geographic Routing Protocol (GRP) [7] divides the network area into quadrants and layers. Each quadrant on an upper layer is organized by four quadrants of sublayer. The location information of the nodes was obtained using initial flooding. While sending a packet towards the destination, the location of forwarder node and the sink node are essential. If both of them are in the same quadrant, the forwarder node chooses the closest neighbor to the sink. If the forwarder node and the sink node are in different quadrants, the upper layer quadrant helps routing.

The Shortest Path Based Geographical Routing (SPGR) [8] algorithm is another geographic routing based protocol. While sending a packet from source to destination it assumes an existing of the Euclidean virtual line. When selecting the closest neighbor of the forwarder node, the coverage area of the forwarder node and the neighbor node, and the distance between the neighbor node and the virtual line are considered. The algorithm selects the node, with the minimum intersection area and with the shortest path between source and sink.

2.2.2 Predictive based forwarding

Other than these there are some related VANET protocols which can be listed as MORA, MOPR, NGRP, DGRP, GROOV. The main difference between them and related MANET protocols is the high speed of the nodes. VANET protocols mostly designed in a predictive mode, the sender node makes a prediction according to the speed and the movement direction of its neighbors.

A Movement-Based Routing Algorithm (MORA) [9] is the routing protocol, which was offered for Vehicle Ad Hoc Networks. MORA uses the functional, which is calculated as the linear combination of two node parameters: speed and direction; and the metric, which is the weight function of the nodes and provides fair load distribution.

Movement Prediction-based Routing Concept (MOPR) [10] into consideration the stability of links or paths along which the packet can be transferred. Using this concept forwarder selects the neighbor node with the high Link Stability parameter. LS parameter depends on the lifetime of the path and route validity time.

In a Novel Geographic Routing Strategy (NGRS) [11] the nodes are aware of the position, direction and the velocity of its neighbor by sending the beacon messages. The protocol was applied to the roadway networks. While the vehicle is on the straightway it uses a greedy mechanism in order to forward the packet, but on the intersections, vehicle selects the forwarder according to the prediction parameters using the speed and the direction information of its neighbors.

Directional Greedy Routing Protocol (DGRP) [12] and GPSR are using two steps of forwarding: Greedy and Perimeter. The main difference of DGRP is that each node gets the speed and movement direction information of its neighbors and uses this data in order to predict the next location.

A Geographic Routing Over VANETs (GROOV) [13] is making possible for the node to be aware about its one-hop neighbor information, like speed, direction, position. It is applicable in a city scenario. On a straight road, the forwarder node estimates Transmission feasibility of its neighbors, using the link quality parameter and range weight. At the intersections the node selection methods change to predictive. It also uses right-hand rule as a recovery strategy.

2.3 Hybrid Routing Protocols

Distance Routing Effect Algorithm for Mobility (DREAM) [14] is the position-based routing technique: each node is aware of the corresponding coordinates of other nodes in the network. Required information is generated only when there is a necessity. The main two concepts of the protocols are the distance effect and mobility rate. Distance effect is based on the fact, if two nodes are far away, there is no need to exchange location information between them frequently because; the expectation of appearing them in the transmission range of each other is low. According to the mobility rate aspect of the protocol, for the nodes with low speed and mobility parameter there is no need to transmit its location information more frequently. Accepting these two facts reduces the amount of control messages transmitting between the nodes. The decision of choosing the next forwarder node depends on the information of its Location Table. Using the location parameters of the nodes forwarder node calculates the direction of its motion and the distance between them. Among its one-hop neighbors, the forwarder

selects the one, which moves towards the destination node: the node use flooding in a restricted zone within the angle. DREAM uses a time-out mechanism and recovery technique. Partially flooding is offered as a recovery technique.

Location-Aided Routing (LAR) [15] in mobile ad hoc networks is based on the location information of the network nodes. The main aspects of this routing technique is the notion of the expected and requested zone. Expected zone is determined as the circle: the center of the circle is the corresponding coordinates of the neighbor node and the radius is the speed of the node. Requested zone is used for the flooding within it. The larger is the requested zone, there is more probability of successfully delivering of the packets, but at the same time, it means route discovery overhead. Based on the choosing the requested zone area, two LAR schemes are proposed in this work: In the first scheme, the requested zone has the minimum area and includes the location of the forwarder node and the expected zone of its neighbors. In the second version, the size of the requested zone is determined during the packet transmission process. Along with the location information in the second scheme, the distance between the neighbor node and the destination. Each time the forwarder chooses the neighbor with the distance toward the sink less than the previous one.

Single Path Flooding Chain Routing in Ad Hoc Networks (SPFCR) [16] also uses geospatial location information of the nodes in the network. The main idea behind this technique is based on that retransmitting the packet within the area is more robust than towards the one node predicting its future location. Instead of using a single path for transmission, each time when node receives the packet, it covers with the flooding the area of expected region.

DOA: DSR over AODV Routing for Mobile Ad Hoc Networks [17] is the hybrid version of DSR and AODV routing protocols. As we mentioned above, both of these techniques are reactive protocols. Taking into account weak and strong sides of both protocols, Waypoint Routing technique was proposed, where, the route from source to destination consists of the segments. In each segment a few forwarder nodes are located. DOA acts like AODV in the intrasegment sections, and as a DSR in the intersegments sections. AODV is more applicable for the large networks and it uses less header overhead in a comparison to the DSR, as a result in the intrasegment

sections it performs better results, while DSR is able to apply multiple path routing, and intersegment section is more applicable for it. In other words, DOA is a combination of DSR and AODV, which performs as one of them depending on the relations of the forwarder and neighbor nodes. In a case when the forwarder and neighbor nodes are located in the same segments, DOA acts like DST, but in a case when they are situated on the neighbor segments, it acts like AODV.

3. A NEW ENERGY-EFFICIENT SHORTEST PATH BASED GEOGRAPHIC ROUTING TECHNIQUE (ESPGR)

The proposed routing technique is applicable in a mobile environment. Mobile node changes its location from one point of network to another randomly or according to the predefined trajectory. It can change its coordinates and continue to communicate with other network nodes. In the technique introduced here two further sensor nodes communicate via multiple hops from intermediate nodes. The intermediate nodes that take active part in data transmission are chosen based on the closest neighbor selection function.

The technique introduced here is developed based on the neighbor selection method of SPGR. As we mentioned above in the previous chapter, SPGR selects the neighbor node with the minimum covered area, according to the transmission range and the distance between the neighbor node and the virtual Euclidean line drawn between the source-target pair.

Theoretically, delivering the packet along the shortest path between two nodes must guarantee low delay and high performance. But in a practice it can result with a congestion along the path and a long queue of packets. Especially, in an ad hoc networks, where the devices cannot have an interruptible connection with a power source, the battery lifetime of the nodes along the shortest path will decrease very quickly. Using of the Euclidean line concept allows to forward the packet to the neighbors which are not far from the shortest path.

In the technique introduced here, we have used the idea of virtual Euclidean line and have changed local search technique parameters. Instead of the minimum covered area an active node calculates the distance from the neighbor node to the destination and the Euclidean line. It selects the neighbor with a minimum value of a distance combination for data transmission between a pair of pre-defined source and target locations.

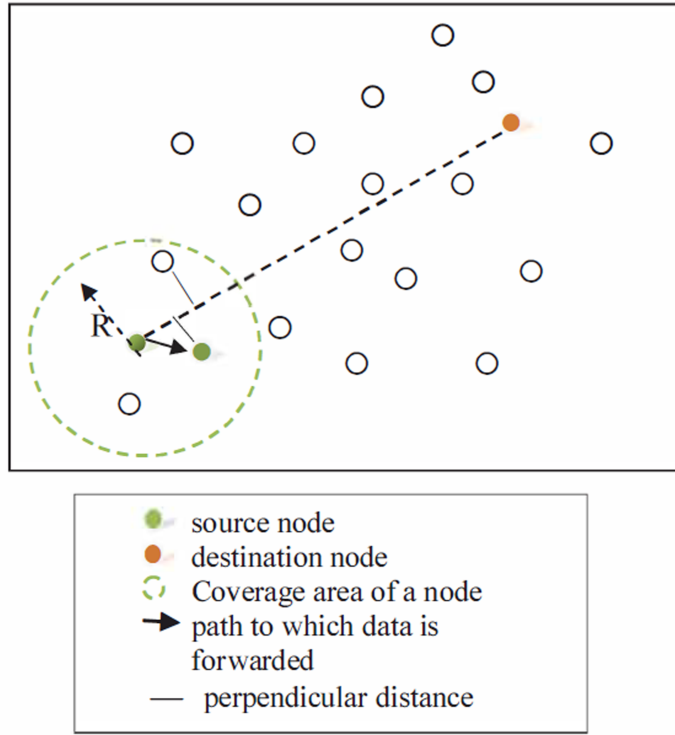


Figure 3.1: Working mechanism of Shortest Path based Geographic Routing (SPGR) [8]

Figure 3.1 and Figure 3.2 present the working mechanism of the distance parameter selection of SPGR and ESPGR. As you can observe, in Figure 3.1 (a) the forwarder node detects the node in its transmission range with the minimum covered area, i.e., the node which is the farthest from it; and also the closest to the virtual line. Figure 3.1 (b) demonstrates the proposed technique. The forwarder node calculates the distance from the next potential forwarder to the sink and to the virtual line (shown in red in Fig 3.2). The energy efficiency parameter was also considered in a design of the technique introduced. We have used energy aware metric to balance energy consumption, and achieve energy efficiency of the whole network. The forwarder node among its neighbors selects the one with the highest energy level. We use a simple energy model in which every node starts with the same initial energy budget, and transmitting or receiving a data packet consumes the energy. The nodes do not have the stand-by position. While the waiting period (idle) each node also loses the energy. The network node which has the energy level below the fixed threshold energy level are not able to forward or receive any packets, forwarding of the packet through

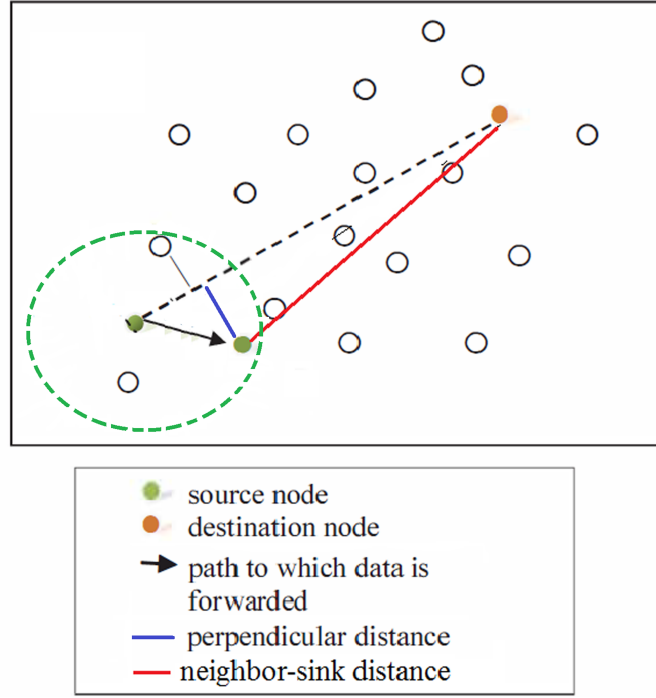


Figure 3.2: Working mechanism of Energy-efficient technique based on SPGR (ESPGR)

them is not possible. Considering of the energy level in the selection function allows to balance the energy consumption across the shortest path.

Thus, the selection function of the neighbor node is the linear combination of the distance and energy parameters and is shown below:

$$f = w_1 * d + w_2 * e; \quad (3.1)$$

$$w_1 + w_2 = 1; \quad (3.2)$$

$$d = 0.5 * distance(neighbor, sink) + 0.5 * distance(neighbor, line); \quad (3.3)$$

where, w_1 and w_2 are the weight values; d represents the distance; e shows the remaining energy level of the corresponding node. Distance is considered as the function giving the Euclidean distance between the input parameters.

w_1 and w_2 values are selected according to the demands of the network. They can be adjusted to emphasize minimizing path length to the destination or energy consumption of the nodes. The higher value of weight makes the related parameter more affective.

In a network with the strict energy-efficiency demand, w_2 is greater than w_1 . However, in a network with low delay demands, w_1 is greater than w_2 .

When the packet receives the data packet, it calculates the value of function according to the Eq. 3.1. for all its neighbors which are determined in its neighbor table. The neighbor with the minimum value of neighbor selection function is chosen as the next forwarder node. Once the next node is chosen, the data from the source along with the coordinate information of the source and destination node is sent to it. Then data transfer commences between the present and the next selected sensor node. The process is repeated until the chosen sensor node is capable of delivering the data packet to the destination node.

Each position of the network node is marked by GPS. In order to get the initial position of every reachable node within the network a flooding packet will be sent out all nodes in the network. Each node has information about its neighbors' location during packet transmission due to the periodic "Hello" messages with its position information to all its neighbors and this informs a node of all its neighbors as well as the position of each neighbor node and at any time. The rate of the Hello packets depends on the mobility parameter of the network nodes: when a node moves more than the threshold distance or after passing some time it broadcasts the hello packets with its location information in it. Exchanging of Hello packets within the network each node rearranges their neighbor table.

A backtracking approach is also used in proposed method. If the node cannot find any neighbor for resending a packet, it sends the packet to the previous forwarder in order to find the other most preferable route towards the destination node. This process will continue recursively until there is not another alternative route. If the new path is not available after all backtrack attempts the node discards the packet. The main advantage of ESPGR is that it chooses the neighbor, which is in the direction towards the destination, due to the focusing on the minimal distance between the neighbor and the destination. But in SPGR the main aspect is the minimum common covered area of the forwarder node and its neighbor, i.e., the node selects the farthest one as the next forwarder. As a result, between two nodes with the same value of the distance among the neighbor and the Euclidean line, the forwarder node can send the packet

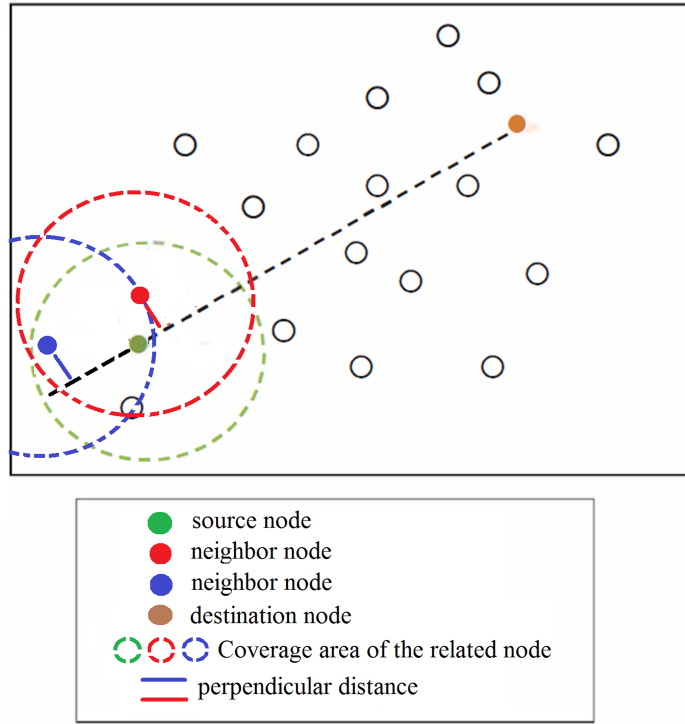


Figure 3.3: Difference on the working mechanism of SPGR and ESPGR

to the neighbor, which has minimum overlap with it, but is situated on the opposite direction from the sink. Figure 3.3 illustrates the possible scenario: According to the SPGR, the source selects the "blue" neighbor, because the distance between "blue" node and source is less than the distance between "red" neighbor and the source. It means, the overlap of the covered areas is less for the "blue" node, but the direction of the forwarding is the opposite from the destination. Consequently, the packet is sent along the longer route, and the number of the dropped packets and hop number per route increase. However, according to the ESPGR, the source will select the "red" node, because the distance between the "red" node and destination is less than the other one. So, the route of the packet will be directed towards the destination point.

4. RESULTS OBTAINED

In the previous sections, we mention the design principles and the properties of the energy efficient shortest path based routing technique. In this section, we present the simulation environment and the performance comparison of the proposed techniques with the others.

4.1 Simulation Environment

Simulation environment was developed using OPNET 18.02 (Optimized Network Engineering Tool) [18] [19] network modeler. OPNET provides a comprehensive possibilities for design simulation and analysis of network models and communication systems, for deployment and configuration of routing protocols. It is the industry's leading network simulation commercial software.

The OPNET software package is implemented in C programming language with the features of object-oriented approach and are widely used for research and development of emerging networking technologies; for performance evaluation, testing, and debugging of communication networks, protocols, and applications. It offers a large scale of constructions for the design and modeling of distributed systems and networks, for study system behaviour and performance and supports all major network types and technologies. Communication networks in OPNET have a hierarchical structure with a model specification editor, modules, which can be customized according to the needs of users. Figure 4.1 presents the basic object hierarchical structure in OPNET. Graphical editors can show the mapping design of the node models and etc. OPNET also automatically bring forth the animation of the simulation: the changes of the network can be viewed in a real-time. The network system investigated in this work is applicable in MANET networks. OPNET can provide a wide range of the implemented MANET protocols with an open-source code, such as AODV, GRP, OLSR, TORA, DSR.

OPNET Object Hierarchy

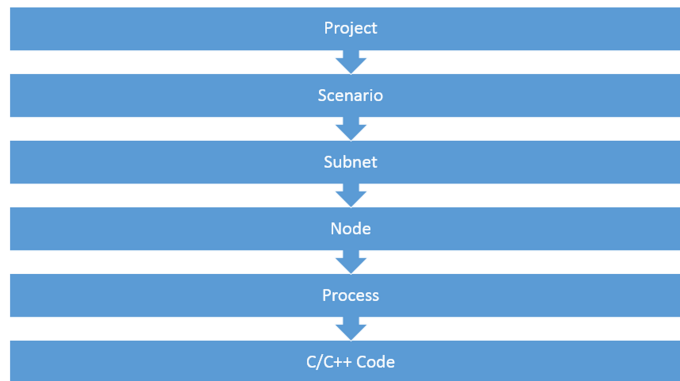


Figure 4.1: OPNET object Hierarchy.

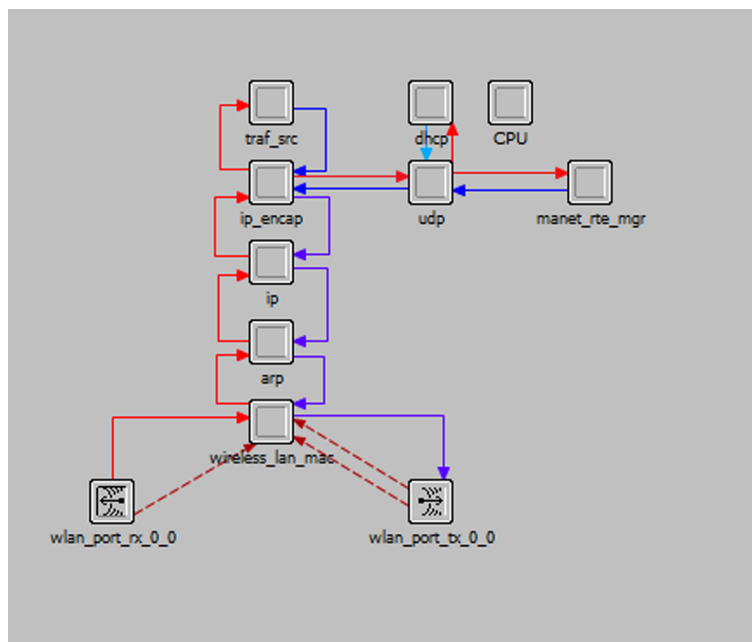


Figure 4.2: OPNET MANET Routing Protocols.

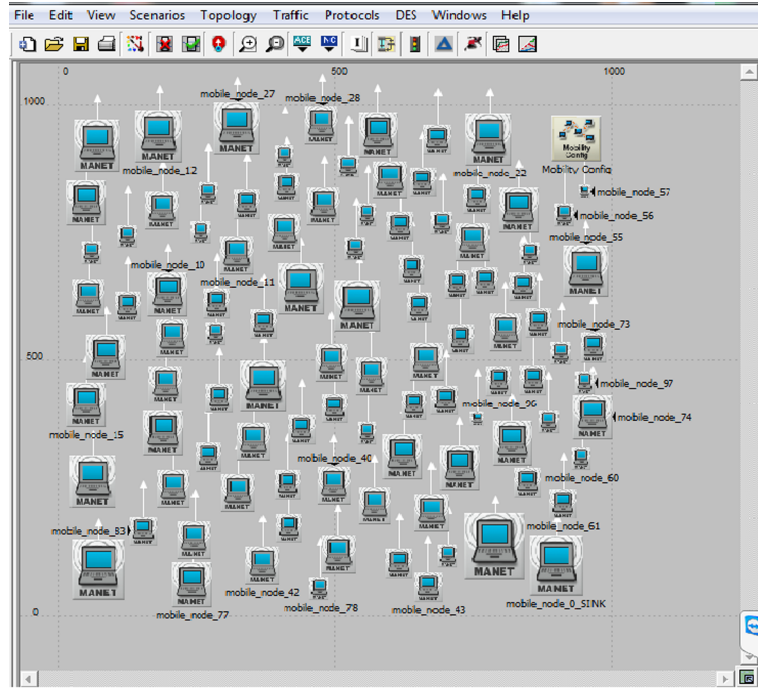


Figure 4.3: Network Topology in OPNET.

In our simulation we have used *manet_station_adv* node model. Figure 4.2 presents the node model of the *manet_station_adv*.

4.2 Network Topology

Simulation area is taken as a rectangular area with a size of 1000x1000 m. 100 nodes are distributed randomly within the network area as shown in Figure 4.3. Transmission range of each node is set to 200 m. Nodes have the equal energy levels depending on the scenario. The nodes lose energy only while sending or receiving data packets or waiting position. In simulation scenarios, both mobile and static nodes are employed. In the mobile scenarios Random Waypoint Mobility (RWM) model is used to realize mobility within the network range: the speed of the nodes is changed uniformly between 0-20 m/sec, the pause time of nodes is taken as 30 sec. The nodes begin to move from the first second of the simulation. Position request timer of the nodes is 50 sec and while moving more than 50 meters the nodes send hello packets in order to aware its new neighbors. The duration of each simulation is taken as 1300 sec. The scenarios are generated with six source nodes and one sink node. All of the source nodes generate the MANET traffic with the same distribution in each scenario.

4.3 Performance Results

The results presented are the average results of the simulations. The source nodes generate the traffic with the following distributions: Exponential distribution with the average values of 3, 5, 10 sec and the Pareto distribution with parameters (2, 1) sec and (1, 0.5) sec. The technique introduced is compared with SPGR and GRP. In the simulations, the quadrant features of GRP are not used: the protocol is compared in terms of neighbor selection method, GRP selects the neighbor according to the closest Euclidean distance.

The performance of protocols are tested employing three scenarios:

- Scenario 1. Static environment, where all the nodes are static;
- Scenario 2. Partially mobile environment, where half of nodes are mobile, the rest are static;
- Scenario 3. Dynamic environment, where all nodes are mobile.

The initial energy level in the partially mobile scenarios is 500 mAh and 1000mAh for dynamic scenarios. In the mobile scenarios the energy level of nodes decreases very fast, hence, for more relevant simulation results we increased the energy level of the nodes in the dynamic scenarios.

As energy consumption levels of different operating conditions, we used the values of Tmote Sky sensor node [20] [21]. The battery supply of Tmote Sky sensor is 2xAAcells. Table 4.1 presents the corresponding energy consumption parameters of sensor nodes. As shown in the table, sensors spent 23 and 21 mA while receiving and transmitting packets appropriately. In waiting position, power consumption is 1200 μ A. In our simulation we did not use duty-cycling; i.e, all the sensors are turned on during the whole simulation process, there is no stand-by position for the sensors. In the scenarios packets are generated according to the exponential distribution and the Pareto distribution. The routing protocol introduced (ESPGR) is compared with the geographic routing protocol without quadrant integration (GRP) and the shortest path

	MIN	NOM	MAX	Unit
Supply Voltage	2.1		3.6	V
Supply Voltage during flash memory programming	2.7		3.6	V
Operating free air temperature	-40		85	°C
Current Consumption: MCU on, Radio RX		21.8	23	mA
Current Consumption: MCU on, Radio TX		19.5	21	mA
Current Consumption: MCU on, Radio off		1800	2400	μA
Current Consumption: MCU idle, Radio off		54.5	1200	μA
Current Consumption: MCU standby		5.1	21.0	μA

Table 4.1: The Operating Conditions and used energy levels for Tmote Sky sensor node.

based geographic routing (SPGR). Energy constraints are also integrated to the GRP and SPGR. The results are examined in terms of delay, throughput, number of hops per route and the number of received packets.

4.3.1 Results under the exponential traffic

The probability density function of the exponential distribution is as follows:

$$f(x; \lambda) = \begin{cases} \lambda e^{(-\lambda x)}, & \text{if } x \geq 0. \\ 0, & \text{if } x < 0. \end{cases} \quad (4.1)$$

where, $1/\lambda$ gives the average interarrival time .

Exponential traffic was generated with the $1/\lambda$ values of 3, 5 and 10 sec on three scenarios: Static, Partially mobile and Dynamic.

Figures 4.4, 4.5 and 4.6 presents the performance results of the scenario 1 under the exponential traffic. In the scenario 1, where the nodes are static, energy consumption level is lower than in the mobile scenarios. The average number of received data packets does not change considerably during the simulation time, the reason of such type of results is the stable position of the nodes: more stable the nodes less energy the nodes expend and the packets transfer along the shortest path. But when we compare ESPGR and SPGR results, it is obvious that the results of the proposed model are much more better.

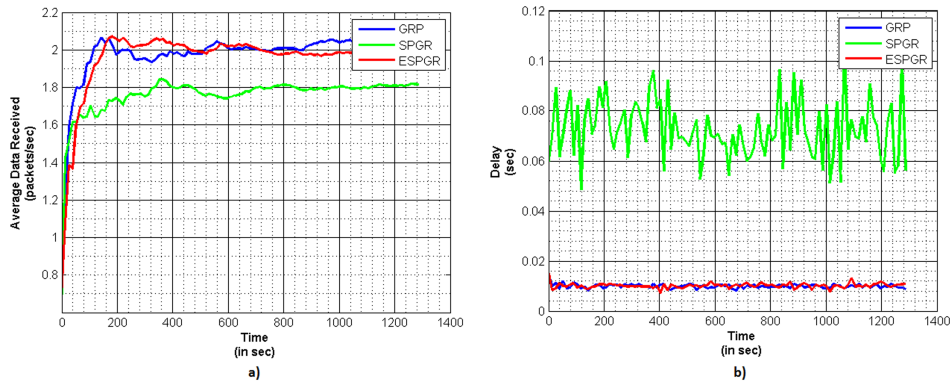


Figure 4.4: (a) Average Received Data and (b) Delay in Scenario 1 under exponential traffic with the average value of 3 sec

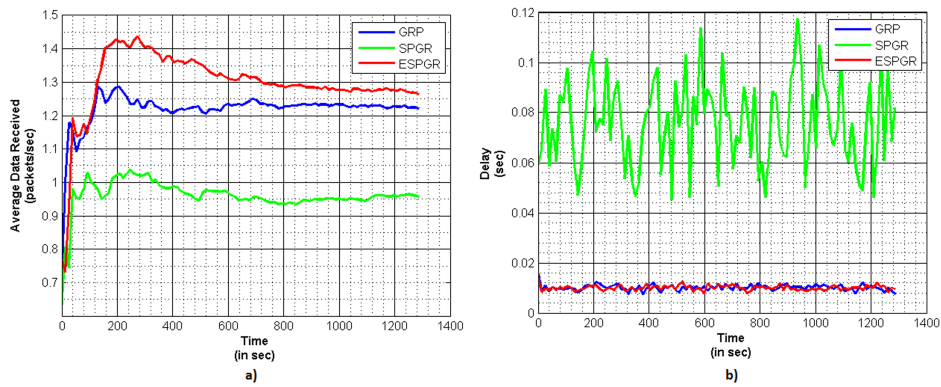


Figure 4.5: (a) Average Received Data and (b) Delay in Scenario 1 under exponential traffic with the average value of 5 sec

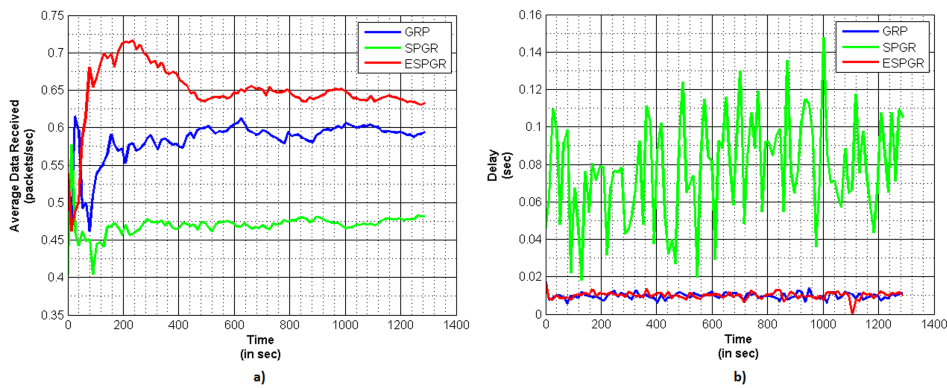


Figure 4.6: (a) Average Received Data and (b) Delay in Scenario 1 under exponential traffic with the average value of 10 sec

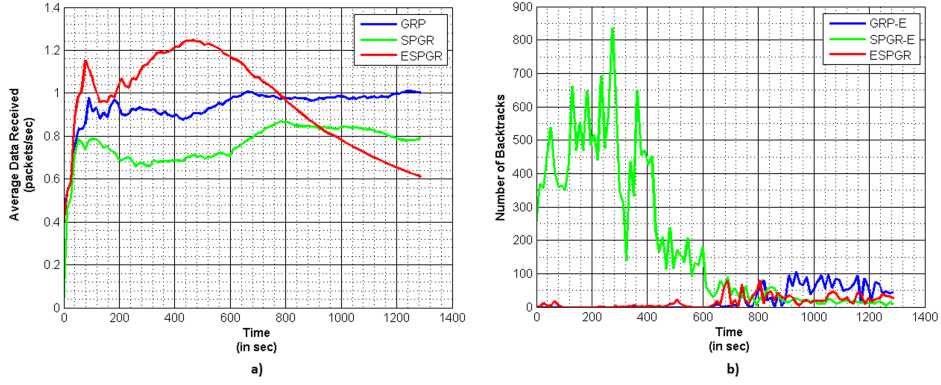


Figure 4.7: (a) Average Received Data and (b) Delay in Scenario 2 under exponential traffic with the average value of 3 sec

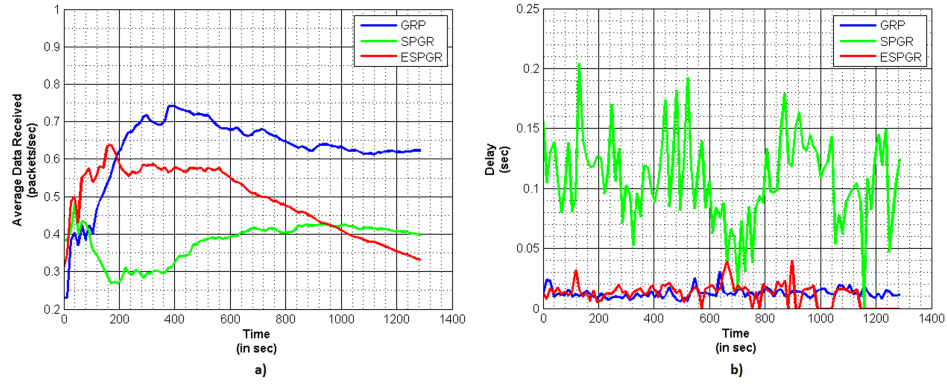


Figure 4.8: (a) Average Received Data and (b) Delay in Scenario 2 under exponential traffic with the average value of 5 sec

Figures 4.7, 4.8, 4.9 demonstrates the results obtained from the scenario 2 under the exponential traffic. From figures it can be seen that delay and throughput performance of ESPGR decreases due to the loss of energy level of the nodes. The dynamic characteristic of the network structure affects the fast decrease of energy level. As we mentioned above, GRP and SPGR does not take into consideration the battery lifetime of the nodes within the network. In a comparison with SPGR, ESPGR displays considerable low delay and high throughput results approximately during first 600 sec under the exponential traffic with the the average value of 3 and 10 sec.

In the Figures 4.10, 4.11, 4.12 we can observe the results of exponential traffic in the scenario 3. This scenario is the most dynamic one, all the nodes are mobile, it means that the energy level of the nodes will decrease faster. In terms of received data energy-efficient algorithms performs as good results as SPGR and GRP; also in terms

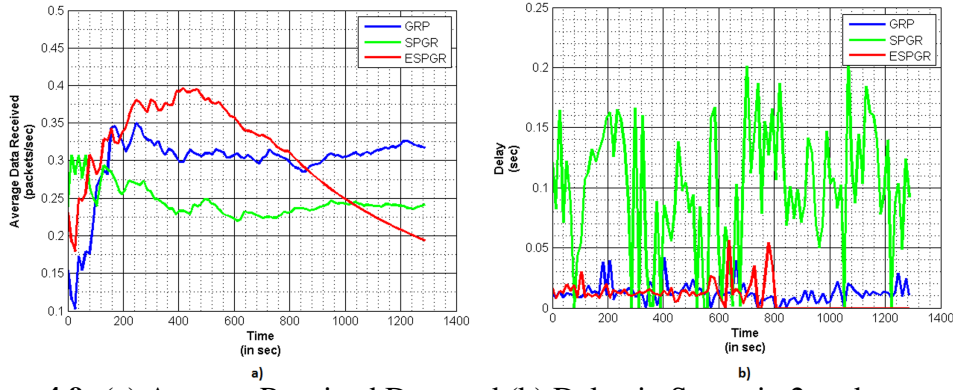


Figure 4.9: (a) Average Received Data and (b) Delay in Scenario 2 under exponential traffic with the average value of 10 sec

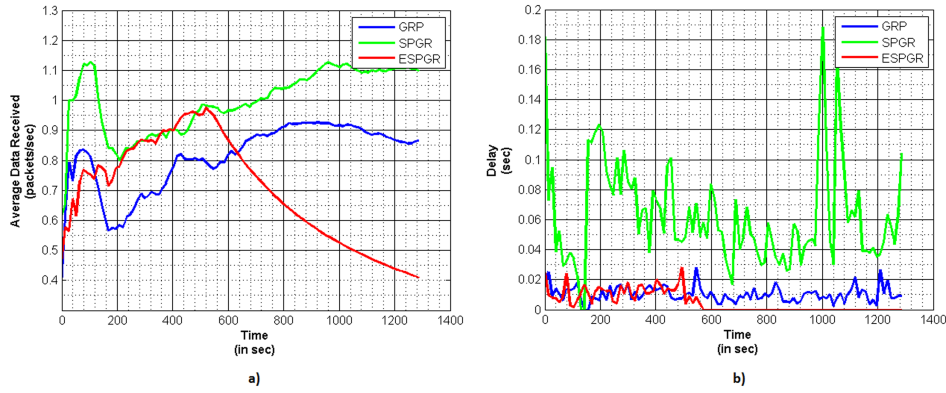


Figure 4.10: (a) Average Received Data and (b) Delay in Scenario 3 under exponential traffic with the average value of 3 sec

of delay energy-efficient algorithm is much better than SPGR. However, due to the reducing of the energy level of the nodes, the performance of ESPGR also decreases.

4.3.2 Results under the Pareto traffic

The probability density function of the Pareto distribution is given as follows:

$$p(x) = \frac{\alpha k^\alpha}{x^{\alpha+1}}; k \leq x; \alpha, k > 0. \quad (4.2)$$

where, k represents the location parameter; α represents the shape parameter of the Pareto distribution. Figure 4.13 represents the probability density function for the Pareto distribution with the location parameter $k = 1$ and $\alpha = 1, 2, 3$. The Pareto distribution process produces independent and identically distributed (IID) inter-arrival times. Pareto distribution model is used to describe bursty data stream.

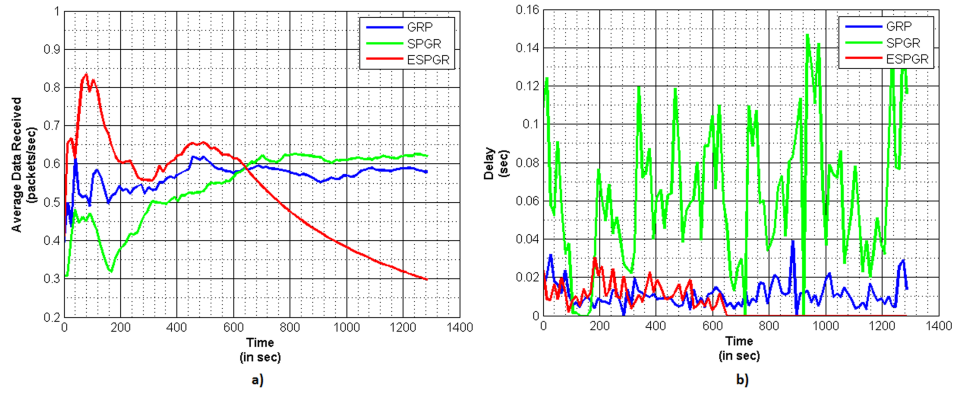


Figure 4.11: (a) Average Received Data and (b) Delay in Scenario 3 under exponential traffic with the average value of 5 sec

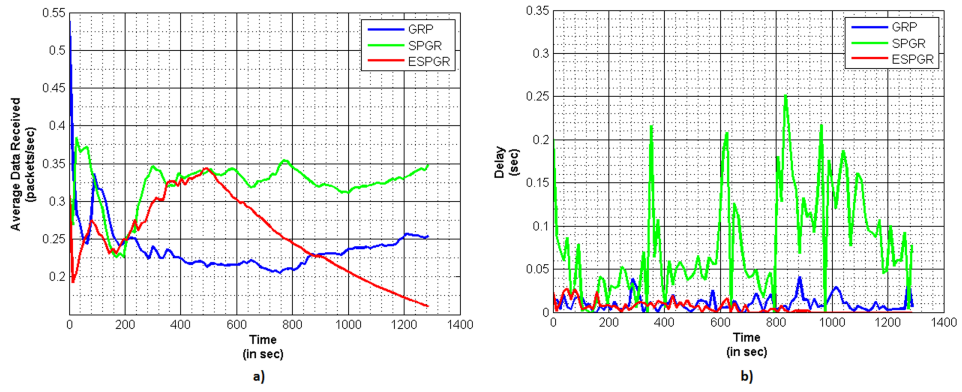


Figure 4.12: (a) Average Received Data and (b) Delay in Scenario 3 under exponential traffic with the average value of 10 sec

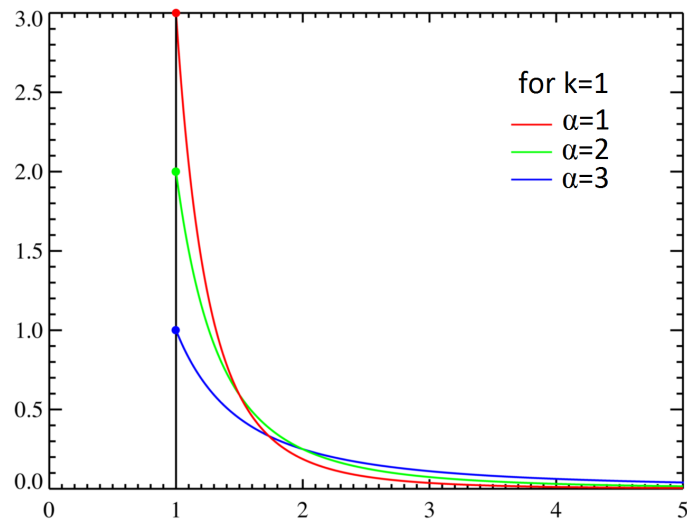


Figure 4.13: Probability density function of the Pareto distribution

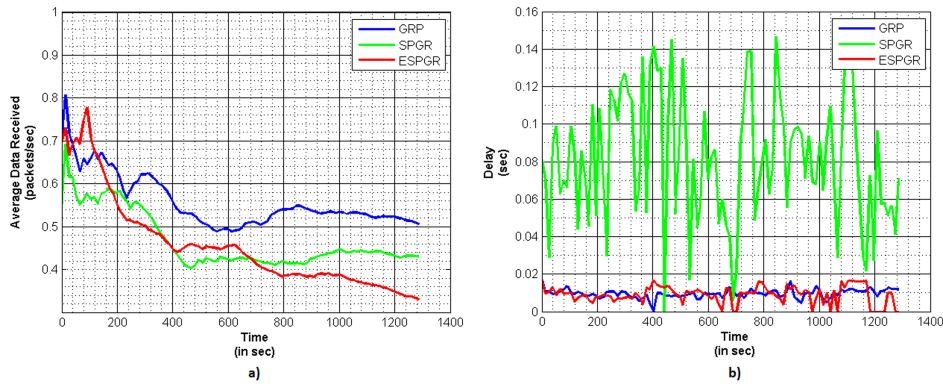


Figure 4.14: (a) Average Received Data and (b) Delay in Scenario 1 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

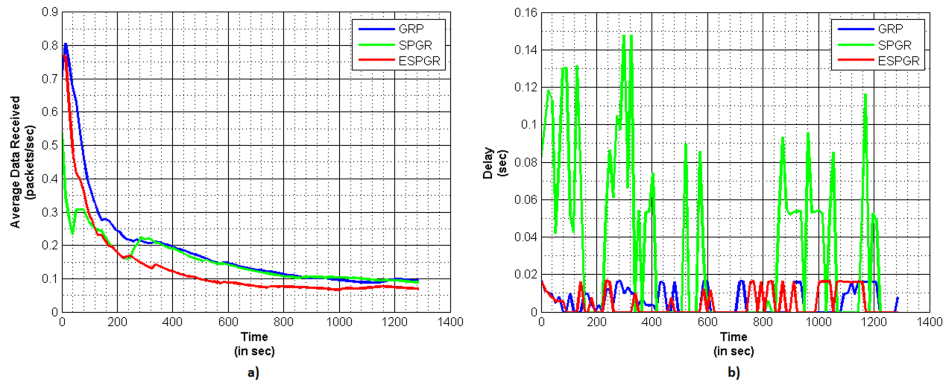


Figure 4.15: (a) Average Received Data and (b) Delay in Scenario 1 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

In our simulations Pareto traffic was generated with the values of location parameter of 2 and 1 sec; and with the shape parameter value of 1 and 0.5 sec appropriately in scenarios: Static, Partially mobile, Dynamic.

Figures 4.14 and 4.15 demonstrates the results under the Pareto traffic for scenario 1. The results of average number of received data packets of ESPGR is not as better as in a comparison with the SPGR. After some simulation time, when the energy level of the nodes along the shortest path decreases, ESPGR send the packet along the alternate paths, and that is reason of reducing of the result when compare it with GRP, which continues to use the shortest path, not considering the energy consumption parameter.

The results for scenario 2 under the Pareto traffic is shown in the Figures 4.16 and 4.17. The results of the Pareto traffic with the parameters (2, 1) shows that ESPGR outperforms the GRP and SPGR in terms of the average number of the received data

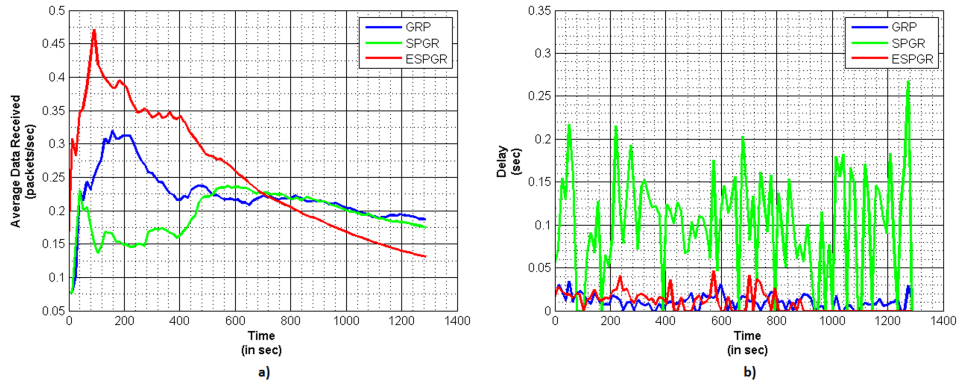


Figure 4.16: (a) Average Received Data and (b) Delay in Scenario 2 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

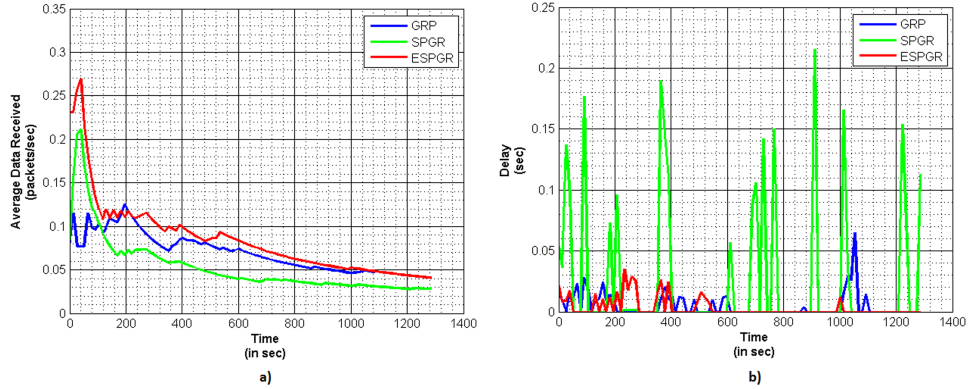


Figure 4.17: (a) Average Received Data and (b) Delay in Scenario 2 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

packets. Decreasing the energy level of the network nodes is the reason of reducing of the throughput level. As we can see, in terms of delay, ESPGR shows better statistics as in the previous figures.

Figures 4.18 and 4.19 represents the statistics under the Pareto traffic for scenario 3. In the scenario, where all the nodes are mobile, ESPGR shows better result for the average number of received data packets in a comparison to the SPGR and GRP, and also in terms of delay it outperforms for the Pareto traffic with the parameters (2,1). We can view that as the remaining energy becomes less ESPGR continues to deliver the packets finding new alternative paths. For the Pareto traffic with the parameters (1,0.5) the results is almost the same, except the delay performance for SPGR, which is very high.

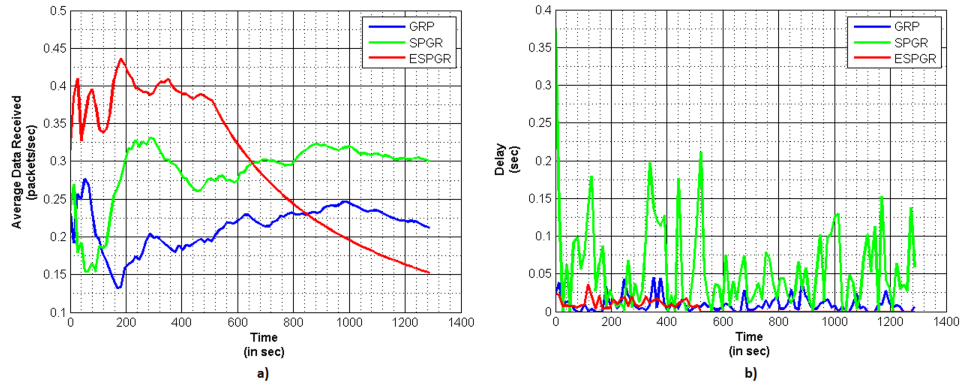


Figure 4.18: (a) Average Received Data and (b) Delay in Scenario 3 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

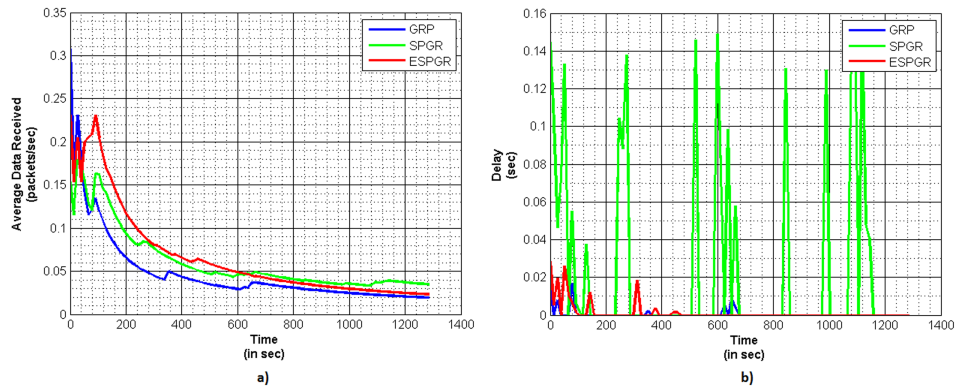


Figure 4.19: (a) Average Received Data and (b) Delay in Scenario 3 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

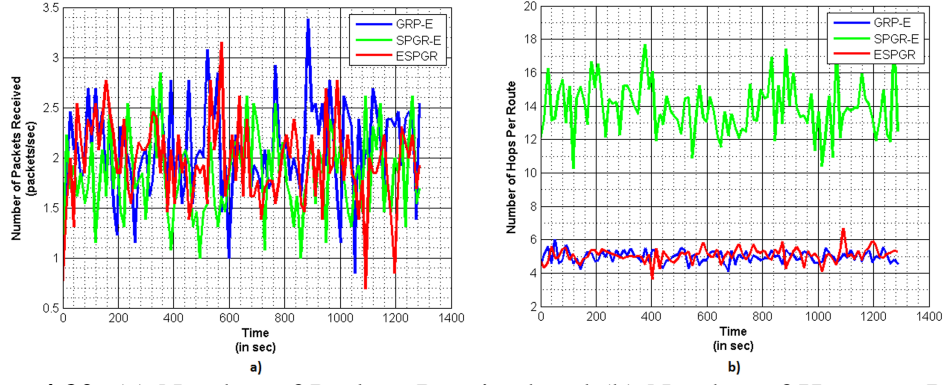


Figure 4.20: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 1 under exponential traffic with the average value of 3 sec

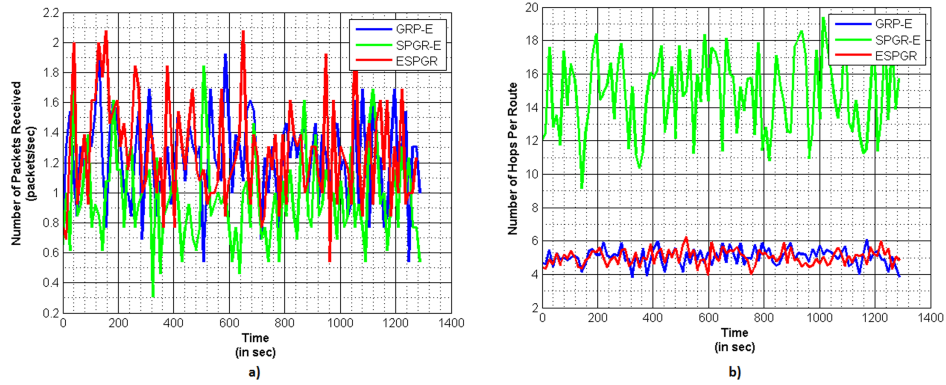


Figure 4.21: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 1 under exponential traffic with the average value of 5 sec

4.3.3 Integration of the energy parameter to the non-energy-efficient techniques

4.3.3.1 Results of the energy parameter integration for the exponential traffic

In order to analyze the routing techniques in terms of the number of received packets, we have integrated energy parameter to the GRP and SPGR: The nodes consume the energy during the packet retransmission or receiving and also in waiting position according to the Table 4.1 as for ESPGR. But at the same time neighbor selection function of GRP and SPGR does not change. During the selective process of the next forwarder node energy level of the nodes were not considered.

Figures 4.20, 4.21 and 4.22 shows the results of the number of received packets and the number of hops per route statistics for the scenario 1. The number of hops per route for SPGR is much higher than the other techniques. The reason of the stability in the graphic is the low energy level changing because of the fixed position of the network nodes.

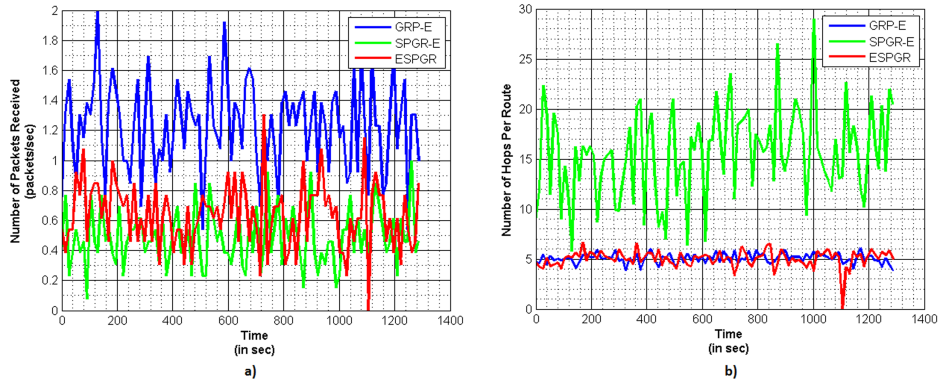


Figure 4.22: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 1 under exponential traffic with the average value of 10 sec

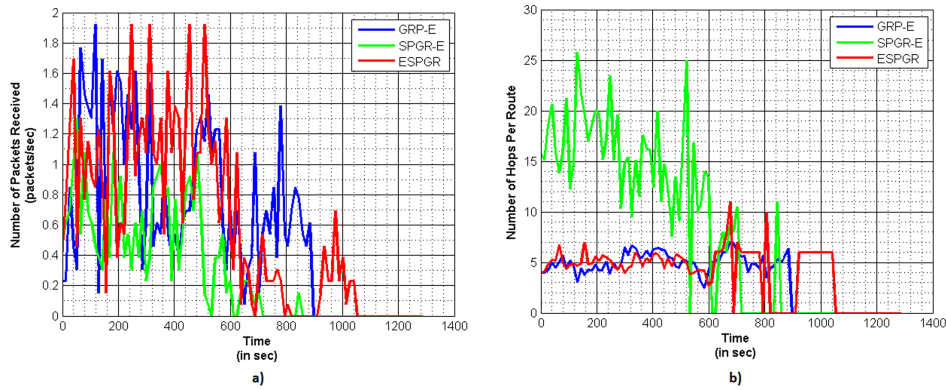


Figure 4.23: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 2 under exponential traffic with the average value of 3 sec

Figures 4.23, 4.24 and 4.25 demonstrate the results of the number of received packets and the number of hops per route in a scenario 2 under the exponential traffic. As we can observe from the figures, performance results reduce as the energy level of the nodes decreases. But ESPGR continues to deliver the packets, when successfully delivering of the packets for the other techniques are failed. Since ESPGR tries to find the most energy reliable path towards the sink, it doesn't exploit the energy of the nodes along the shortest path.

Figures 4.26, 4.27 and 4.28 shows the number of received packets and the number of hops per route in the scenario 3 under the exponential traffic. Scenario 3 is the most dynamic one, where all the nodes are mobile. The shown results of ESPGR is better especially under the parameter 5 and 10, when the network breaks into partitions. In Figure 4.26 SPGR shows better results than the ESPGR, but comparing the number of

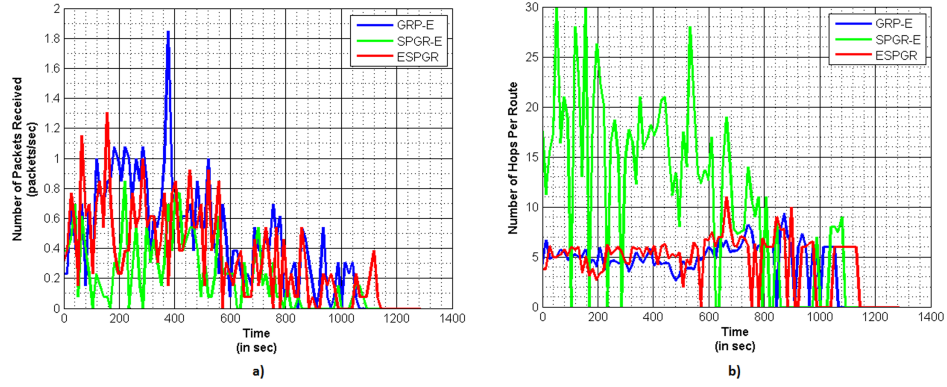


Figure 4.24: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 2 under exponential traffic with the average value of 5 sec

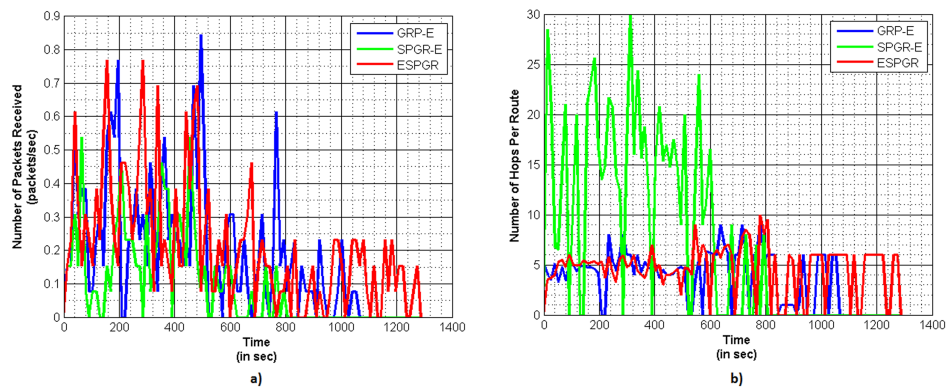


Figure 4.25: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 2 under exponential traffic with the average value of 10 sec

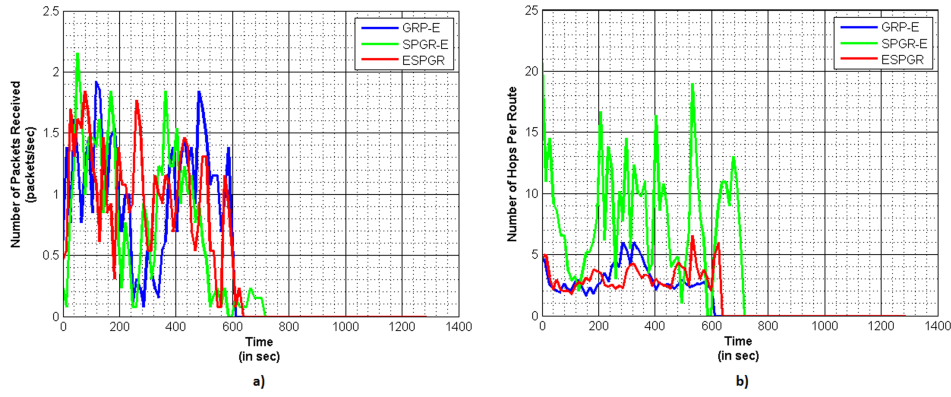


Figure 4.26: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 3 under exponential traffic with the average value of 3 sec

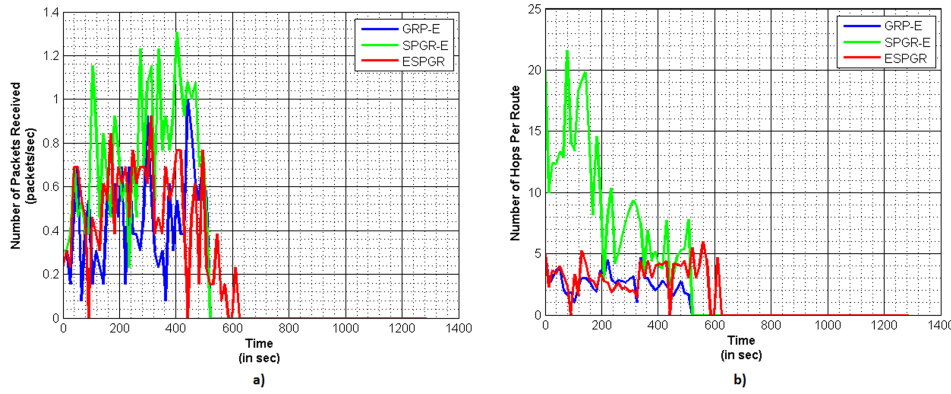


Figure 4.27: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 3 under exponential traffic with the average value of 5 sec

hops per route we can observe that ESPGR has better statistics, which affects the total consumed energy level within the whole network.

In order to understand the behaviour of the protocols we have also analysed the statistic results of the dropped packets and number of backtracks within the simulation time.

Figures 4.29, 4.30, 4.31 display the number of the dropped packets and backtracks for the scenario 2 under the different values of exponential traffic. As we can observe, the number of the dropped packets and backtracks for SPGR is very high. The number of the dropped packets is decreasing over the time, due to the fact that network becomes more stable, but after reducing the energy level of the nodes, the number of the dropped packet began to rise for all the techniques. The number of the backtracks for SPGR is high, because of the high level of the dropped packets, but it decreases when the nodes are not able to forward the received packets due to the low energy level.

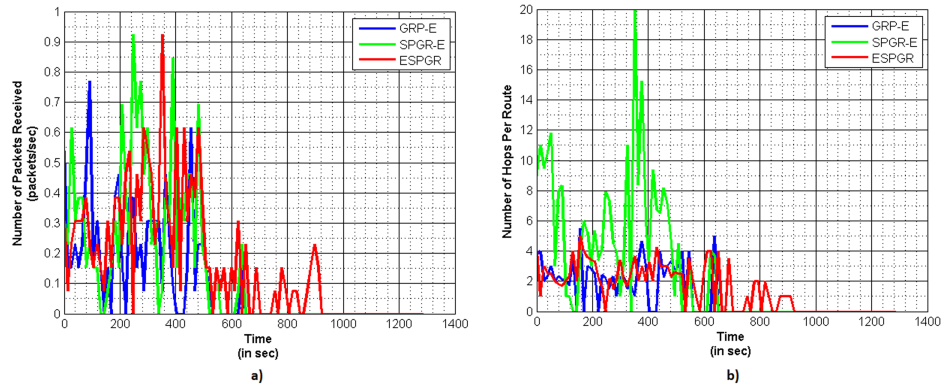


Figure 4.28: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 3 under exponential traffic with the average value of 10 sec

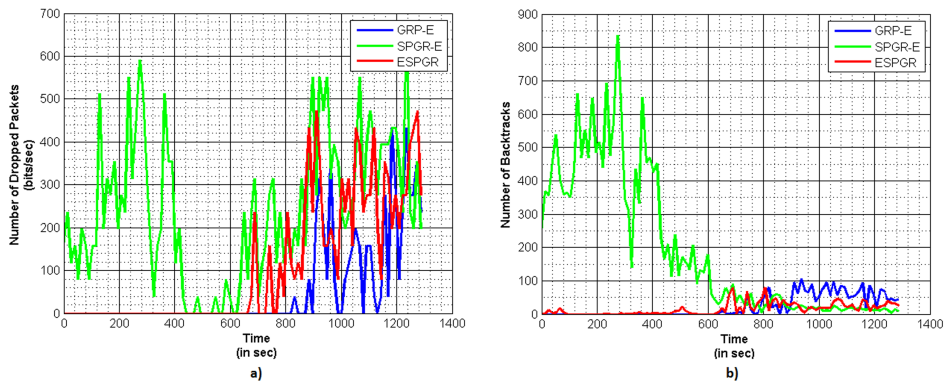


Figure 4.29: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 2 under exponential traffic with the average value of 3 sec

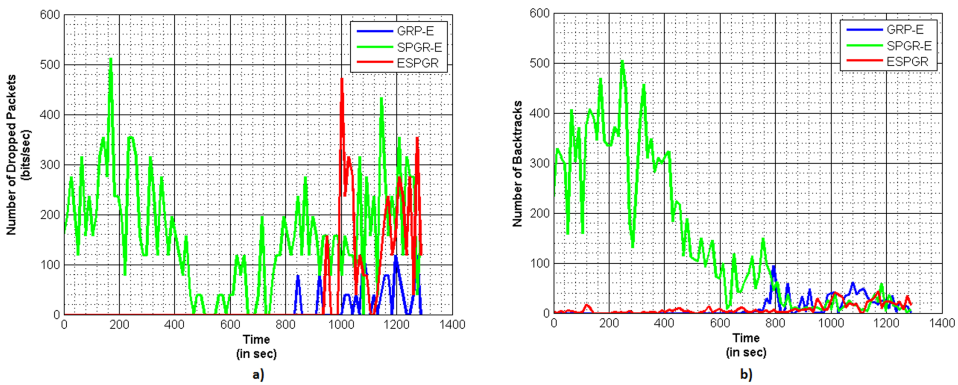


Figure 4.30: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 2 under exponential traffic with the average value of 5 sec

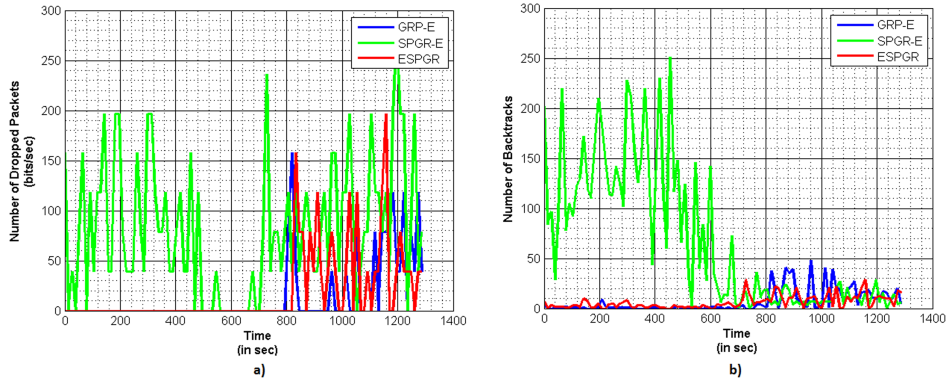


Figure 4.31: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 2 under exponential traffic with the average value of 10 sec

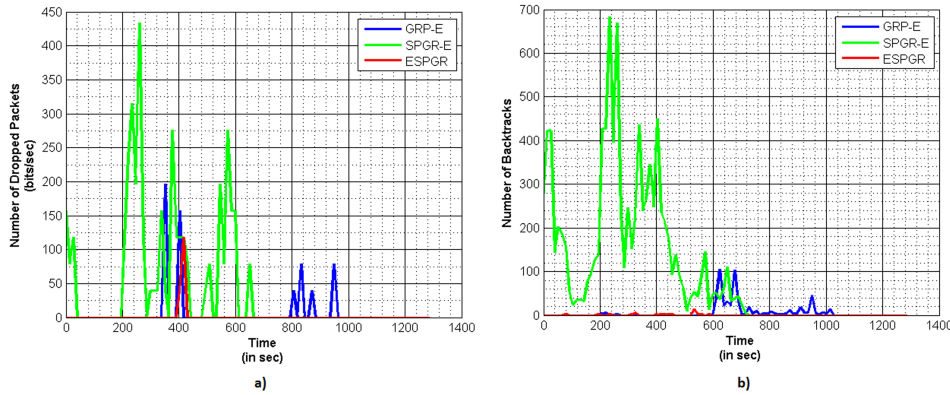


Figure 4.32: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 3 under exponential traffic with the average value of 3 sec

For the Figures 4.32, 4.33, 4.34 where the statistics are shown in the scenario 3, we can repeat the same things above about the scenario 2. In a dynamic environment, the nodes along the shortest path between the sources and the sink changes frequently, as a result, the number of the dropped packets can be lower: the forwarder can find the appropriate neighbor.

4.3.3.2 Results of the energy parameter integration for the Pareto traffic

In the previous simulation results of the Pareto traffic, we compared the performance of the proposed energy-efficient technique with the GRP and SPGR protocols. In order to test the energy-efficiency parameter of the proposed technique. The energy level of the nodes decreases during simulation according to their activities. A node of which energy level is lower than the threshold cannot send or receive packets.

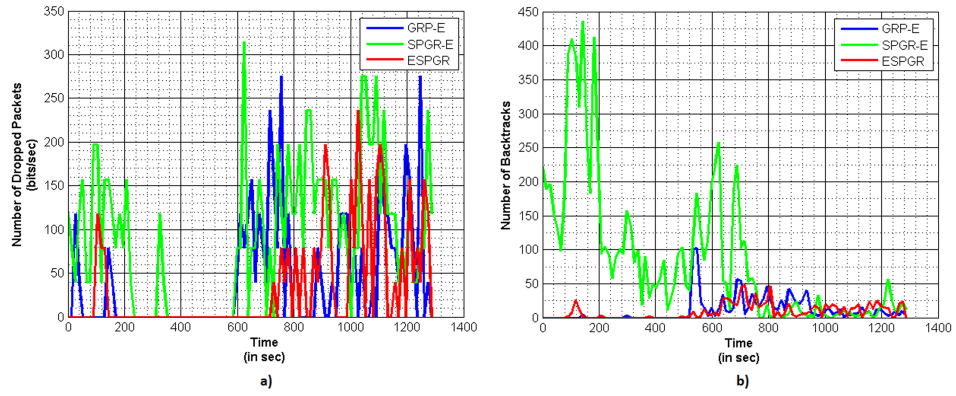


Figure 4.33: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 3 under exponential traffic with the average value of 5 sec

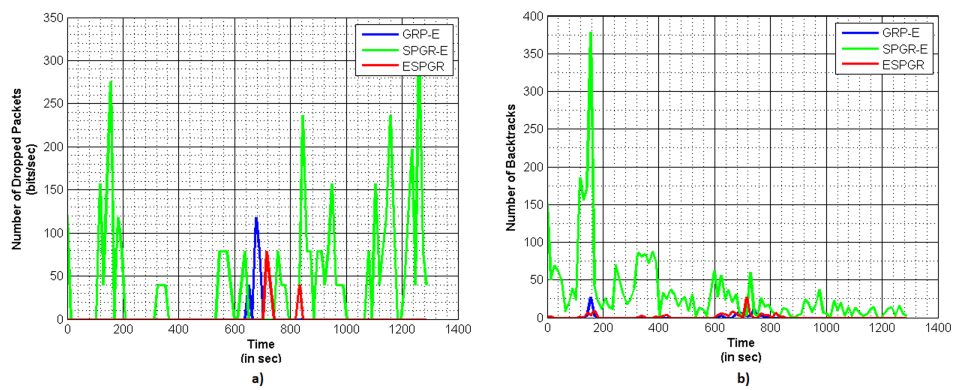


Figure 4.34: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 3 under exponential traffic with the average value of 10 sec

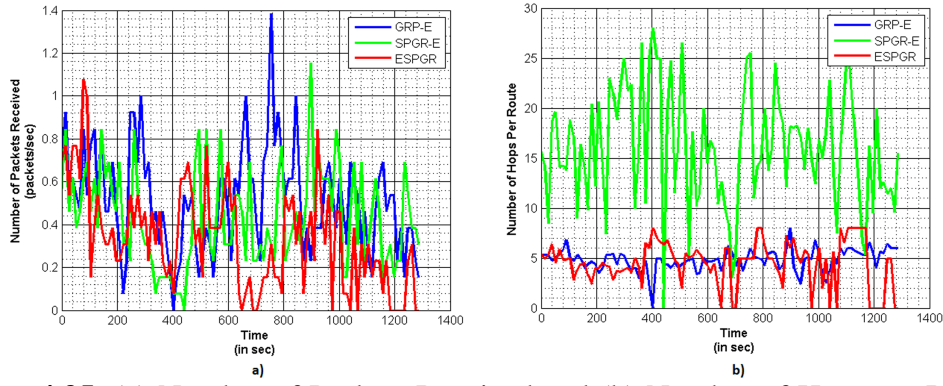


Figure 4.35: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 1 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

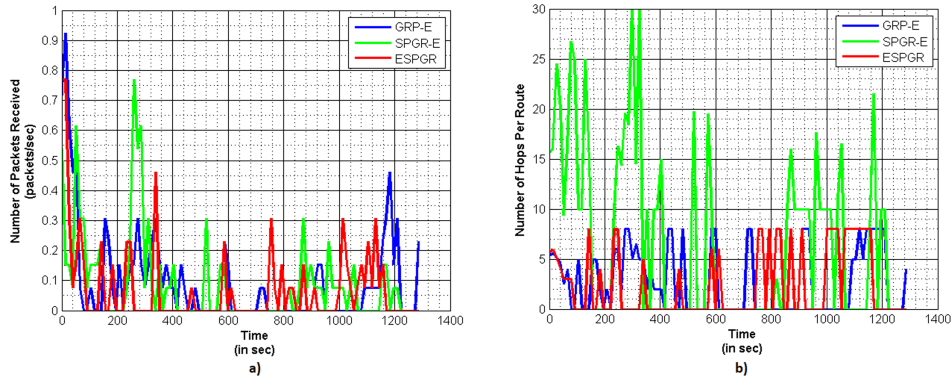


Figure 4.36: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 1 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

Figures 4.35, 4.36 demonstrate the statistics of the number of received packets and the number of hops per route for the scenario 1 under the Pareto traffic. As we are relatively can observe, the number of received packets same for the static environment, but in terms of number of hops per route ESPG displays better results than SPGR.

Figures 4.37, 4.38 display the results for scenario 2 under the Pareto traffic. For the Pareto traffic with the parameters (2,1) the proposed energy-efficient technique can deliver more packets when the network connectivity is less due to the nodes that are not functioning. The nodes along the most used efficient paths lose energy, ESPGR protocol transmits packets along the nodes with high energy level. Since the environment is partially dynamic, the number of received packets prolongs compared with GRP and SPGR. Also, it was observed that the number of hops per route for the each technique decreases over the time for all protocols. For the Pareto traffic with the

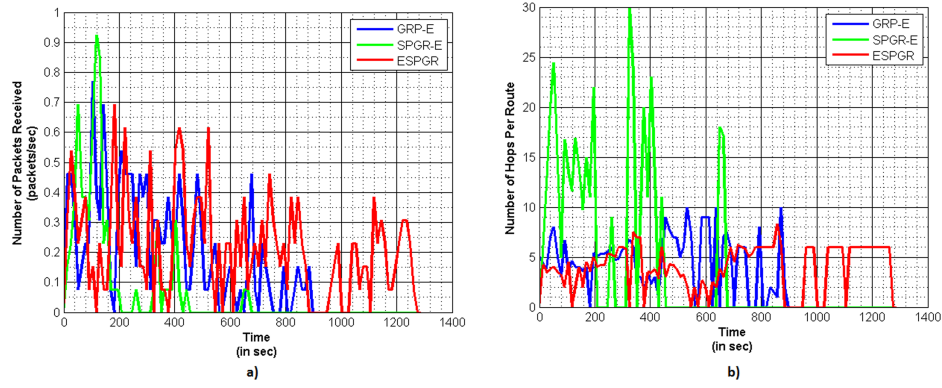


Figure 4.37: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 2 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

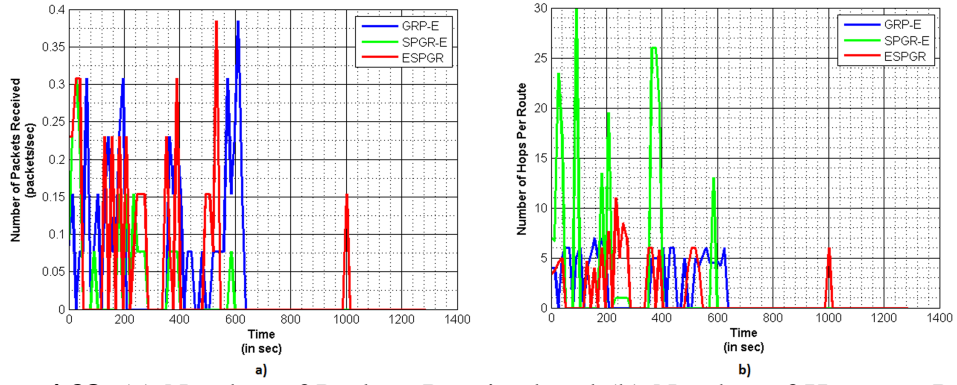


Figure 4.38: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 2 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

parameters (1, 0.5) the number of received packets parameter is as better as GRP, but on the other hand, the number of hops per route parameter outperforms SPGR.

Results for the scenario 3 under the Pareto traffic are shown in the Figures 4.39, 4.40. As in the previous scenarios, the statistics for the Pareto traffic with the parameters (2,1) are much better. The network, which uses ESPGR technique is able retransmit the packet when for the other networks the number of delivered packets is negligible. For the Pareto traffic with the parameters (1, 0.5) SPGR shows better results, but in terms of hop number it fails astern.

Figures 4.41, 4.42 illustrates the results of the dropped packets and number of backtracks for scenario 2. After decreasing the energy level of the nodes, number of dropped packets increases, as a result, the number of the backtracks fall down, because, the forwarder node cannot find the available neighbor for resending the packet. The

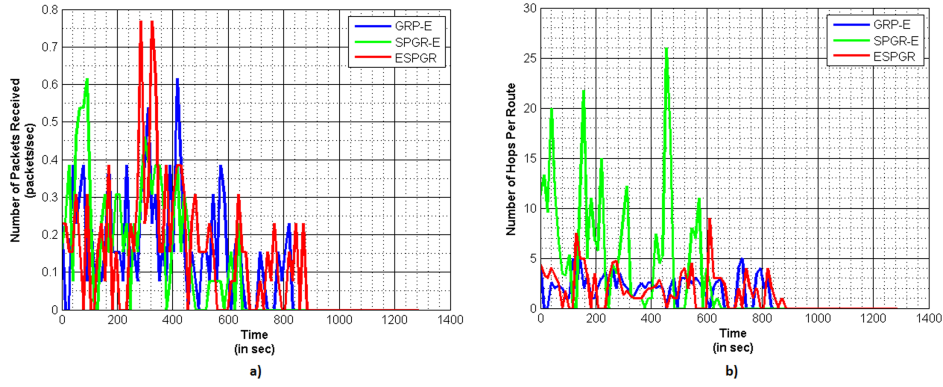


Figure 4.39: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 3 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

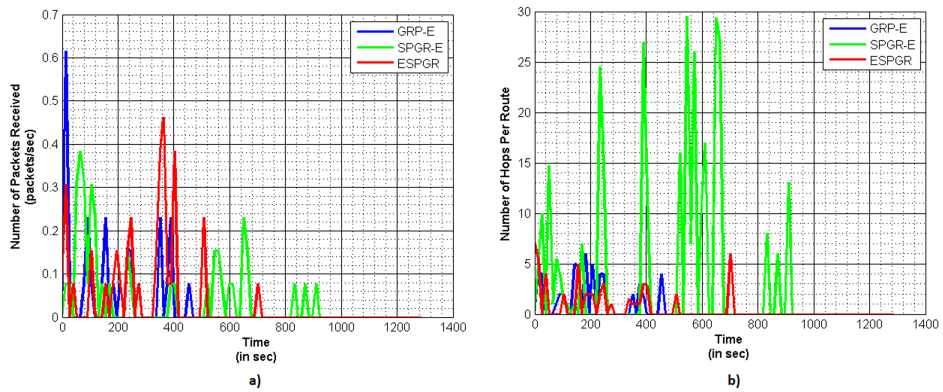


Figure 4.40: (a) Number of Packets Received and (b) Number of Hops per Route in Scenario 3 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

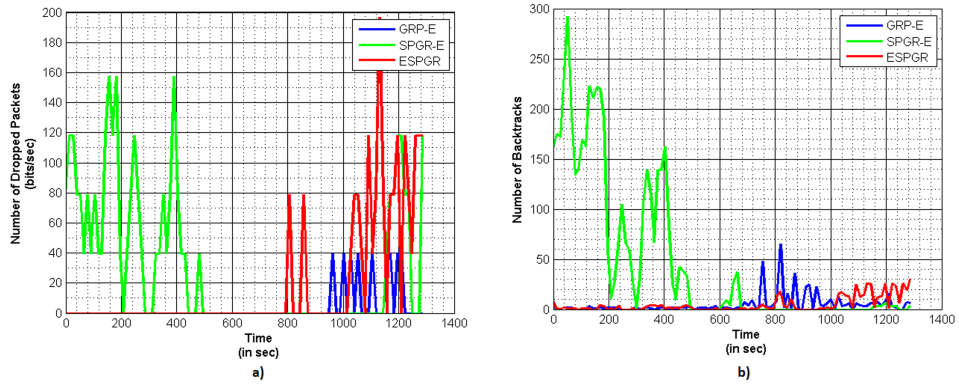


Figure 4.41: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 2 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

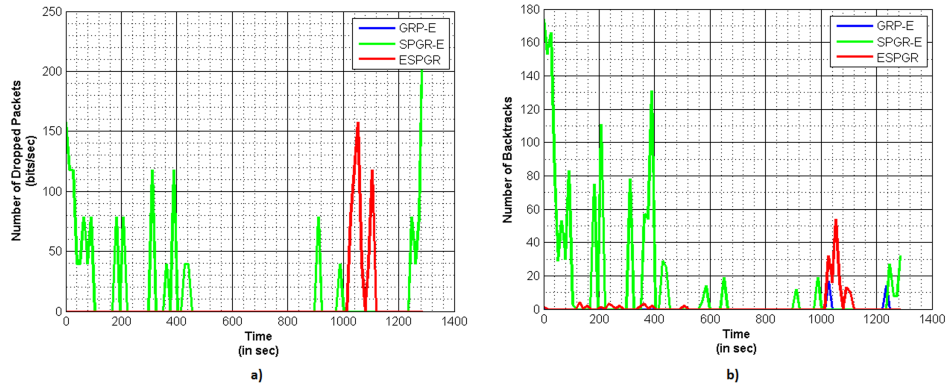


Figure 4.42: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 2 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

graphic of the dropped packets shows that even when the network partitioning has not taken place, the number of the dropped packets is as high as SPGR for ESPGR.

For the Figures 4.43 the results are as follows: the number of the dropped packets becomes higher as the nodes lose the energy, but the number of backtracks for ESPGR becomes higher, which means that the network nodes are able to find the alternative path towards to the destination. In the Figures 4.44 the number of dropped packets and number of the backtracks for ESPGR is negligible.

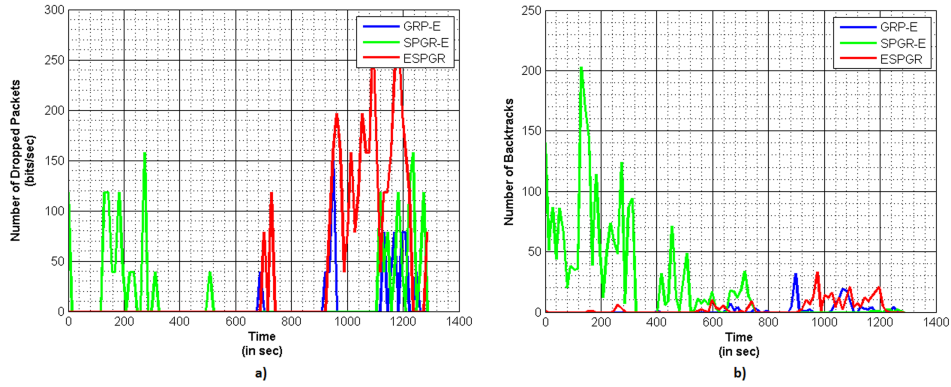


Figure 4.43: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 3 under the Pareto traffic with the location parameter value of 2 sec and the shape parameter value of 1 sec.

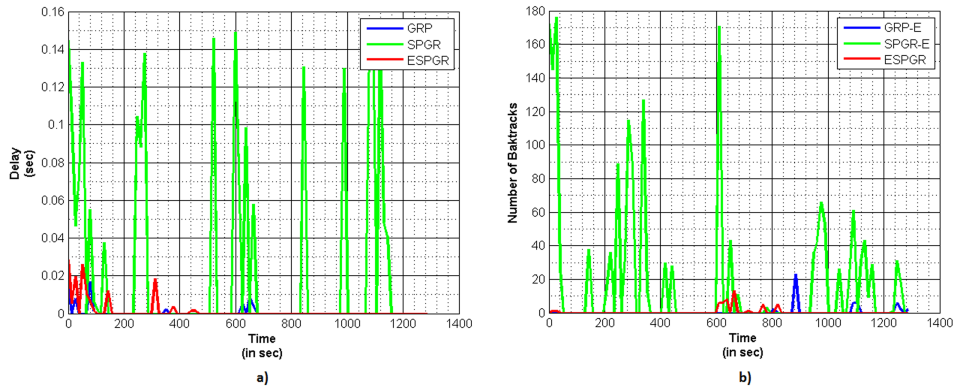


Figure 4.44: (a) Number of Dropped Packets and (b) Number of Backtracks in Scenario 3 under the Pareto traffic with the location parameter value of 1 sec and the shape parameter value of 0.5 sec.

5. CONCLUSION AND FUTURE WORK

In this work a new energy-efficient geographic-based routing technique based on the SPGR technique was introduced. Geographic routing technique is forwarding method which uses the location information of the network nodes in order to realize the transmission of the packets within the whole network. We have presented the updated neighbor selection method for the geographic forwarding in MANET. The distinctive characteristic of the MANET networks is the lack of information about network structure, and mobility feature of the network nodes.

Our selection method used the virtual Euclidean line between source-sink pairs. While the node chooses the next forwarder among its neighbors, it calculates the distance between the neighbor and the sink node; and the distance between the Euclidean line and the neighbor. Including the energy level value of the neighbor node to the selection function we have got an energy-efficient forwarding technique, which tries to balance between resending the packet along the shortest path and degrading of the energy levels of the network nodes. The node consumed energy during receiving, transmitting of data packets and waiting time.

The performance of the technique was studied by using the exponential traffic and Pareto traffic. Traffics were generated with the different values and the effects of the packet sending frequency was examined. Simulation environment was organized as the static, partially mobile and dynamic depending on the mobility parameters of the network nodes. As a result, we have tested the proposed technique not only in a MANET, but also in the static networks.

The results were compared with GRP and SPGR. It was observed that the introduced technique outperformed the others in terms of delay and number of delivered data. Moreover, energy parameter was integrated to GRP and SPGR, and the results showed that, the lifetime of the network using EGRP technique was longer in a comparison with GRP and SPGR.

As a future work, we are planning to work on the ARP routing protocol in order to improve it in terms of energy-efficiency and performance. As we mentioned before, ARP - Angular Routing Protocol - is one of the modified versions of GPSR, which combines the greedy and angular techniques. Though the realization technique was more simple than in GPSR (ARP doesn't use planar graphs), the simulation results for ARP was much more better. We want to analyse the effects of integration of the energy parameter to ARP and the possible improving of the protocol. Also, multi-sink transmission can be considered. Our present work was focused on a multi-source and single sink transmissions. In the future, single-source and multi-sink or multi-source and multi-sink transmissions can be investigated.

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PUBLICATIONS/PRESENTATIONS ON THE THESIS

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