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The Traffic Prediction Multi-path Energy-aware Source Routing (TP-MESR) in Ad hoc Networks

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***Abstract*—**The purpose of this study is to suggest energy efficient routing for ad hoc networks which are composed of nodes with limited energy. There are diverse problems including limitation of energy supply of node, and the node energy management problem has been presented. And a number of protocols have been proposed for energy conservation and energy efficiency. In this study, the critical point of the EA-MPDSR, that is the type of energy efficient routing using only two paths, is improved and developed. The proposed TP-MESR uses multi-path routing technique and traffic prediction function to increase number of path more than 2. It also verifies its efficiency compared to EA-MPDSR using network simulator (NS-2). Also, To give a academic value and explain protocol systematically, research guidelines which the Hevner(2004) suggests are applied. This proposed TP-MESR solved the existing multi-path routing problem related to overhead, radio interference, packet reassembly and it confirmed its contribution to effective use of energy in ad hoc networks.

***Keywords*—**Ad hoc, energy-aware, multi-path, routing protocol, traffic prediction.

I. Introduction

AD hoc network are composed of mobile devices, in other word it does not have fixed-infrastructure, it means there is no time and space restriction compared to wired networks. So, ad hoc network is useful in any situation where difficult to set up the network such as disaster relief, rescue operations, and many other applications [1]. One of character of ad hoc networks is mobility: all nodes in network are capable of movement and can be connected dynamically. Despite these advantages, wireless nodes have limitation related to energy supply. It means that network operation depend on node with limited energy. MBCR(Minimum Battery Cost Routing)[2], MMBCR(Min-Max Battery Cost Routing)[2][3], CMMBCR(Conditional Max-Min Battery Cost routing)[2], PSR(Power-aware Source Routing)[3] are type of energy aware routing to use limited energy effectively. These protocols are developed in phase, and finally PSR is near complete energy aware algorithms using single path routing. Recently, after PSR, multi-path routing technique is developed so it can improve performance of nodes. Multi-path routing has effects on load balancing, fault-tolerance, higher aggregated bandwidth. Especially, the load balancing can reduce traffic overhead by dividing traffics. Also it can distribute energy consumption of nodes to nodes in other local network. The EA-MPDSR analyzes the strong point and a weak point of multi-path routing and applies it. Using two path methods leads to improving of energy efficiency than the existing protocols. But multi-path routing has a problem that related to overhead, radio interference, packet reassembly. Because it uses round-robin type that like almost a parallel transmission.

The proposed TP-MESR uses multi-path routing technique and traffic prediction function to increase number of path more than 2. In this study, we confirmed, solution to problem that caused in multi-path routing is regular sequence packet transmission using one path. For this solution, traffic prediction function which is new load balancing framework is proposed. Also To give a academic value and to propose protocol systematically, the research guidelines which the Hevner(2004) suggests are applied. We have implemented TP-MESR in the NS-2, simulation results showing the effectiveness of the TP-MESR. And it confirmed that effectiveness of TP-MESR is better than existing EA-MPDSR. This study is organized as follows. Section II addresses related studies. Section III present TP-MESR and explain methodology and details of process. Section VI evaluates performance compared to existing protocols. and finally, Section V gives a conclusion..

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II. Related Work

In this section, Existing routing protocol types that related to proposed TP-MESR protocol for ad hoc networks are reviewed: On-demand DSR(Dynamic Source Routing) protocol, PSR(Power-Aware Source Routing) protocol.

A. Routing Protocols in Ad hoc network

The character of ad hoc network is dynamic topology based on wireless networks with node mobility. Each node in networks acts as a router. In other word, all nodes in ad hoc network maintain network connectivity without limitation of place and time. These nodes in ad hoc networks are usually battery-based. Thus extending the battery lifetime and power efficiency is becoming main goals to keep nodes connectivity. A number of studies have been done on routing protocols in ad hoc network environment and recent studies have started to consider energy conservation and battery lifetime [4], [5].

Routing protocols in ad hoc networks generally can be

classified into 2 types, see table I [3]. Table I shows the 2 types of protocol in ad hoc networks and comparison.

TABLE I
TABE DRIVEN AND ON-DEMAND PROTOCOLS

Protocols in Ad hoc Networks		
Type	Table-driven (proactive)	On-demand(Reactive)
Class	DSDV, CGSR	DSR, AODV
Overhead	High	Low
Sleep time	Low	High
Purpose	Low Mobility	Relative High Mobility

Table-driven type is early stage in ad hoc network routing. In this type, each node keeps routing information about other nodes in their routing table. Route discovery process is not necessary when the packet needs to be transmitted. That is, table-driven type has less transmission delay compare with on-demand type. But continuous updates for the latest information cause high routing overhead and lead to increase the energy consumption in the networks. In other words, table-driven protocols are not considered an effective routing solution for ad hoc networks [6]. This table-driven type is suitable for small size ad hoc network with less nodes or wired network. Some of the best known table-driven protocols are DSDV(Destination Sequence Distance Vector [2], CGSR(Clusterhead-Gateway Switch Routing) [7] and so on.

On-demand type is also known as reactive routing. It is proposed to complement disadvantages of table-driven routing protocols. On-demand protocols only perform route discovery process when a new route is needed. Consequently, the routing overhead is reduced. So this protocol is better than table-driven type in ad hoc network with many wireless nodes. However this type has high transmission delay because it needs to perform route discovery process. But on-demand routing protocols are more efficient in energy consumption as compared to table-driven routing protocols. DSR(Dynamic Source Routing) and AODV(Ad-hoc On-demand Distance Vector) are popular on-demand protocols for mobile ad hoc networks [8], [9].

B. On-demand DSR Protocol

DSR protocol is one of the most popular on-demand routing protocol which is based on the source routing [3]. When a node sends data packets to a destination, it checks its routing table first to determine whether it already has a route or not. If there is no route in routing table, it starts path routing process by broadcasting. Advantage of DSR protocol is that they do not have a periodical routing packet, therefore it has less overhead. For this, all nodes in networks keep route cache which is role as a routing table. Figure 1 shows path routing process of DSR protocol.

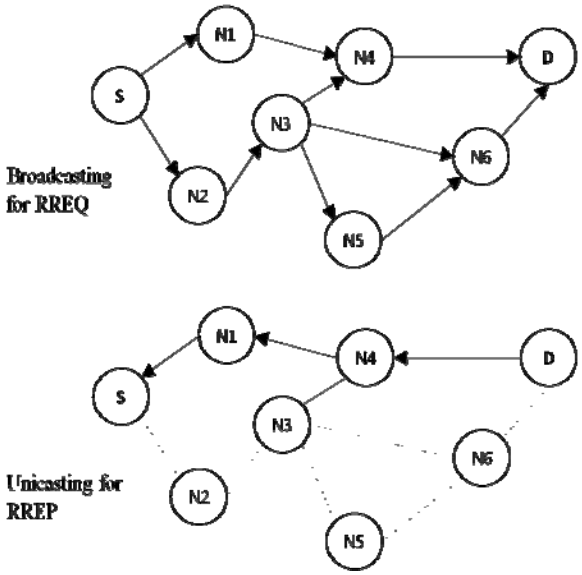

Fig. 1 Path Routing Process of DSR

As seen as figure 1, DSR protocol finds path based on exchange between RREQ and RREP [8]. In DSR protocols, if node does not have route to destination, it issues a route request to all of its neighbors. Neighbor nodes also rebroadcast RREQ, adding their address in the header of the packet. Finally, RREQ arrive at destination node. Destination node only accepts RREQ which is first arrived and rejects other RREQ, so the shortest route can be selected. And then destination node generates RREP and sends to source node with addresses accumulated in the RREQ header. The new path can be set up through such a process. In this process, route cache adds data that route to destination and send it to source node and condition of nodes operation is checked by exchanging the response messages. If there is no response, route discovery phase is restarted by sending a route error packet (RRER). Because of this process, if nodes are changed often, path routing process should be performed and it causes high overhead. Such a high overhead leads to high energy consumption of nodes and the problem is becoming that keep the network for a long time with limited energy. To reduce energy consumption, PSR protocol that related to power-aware is proposed.

C. Energy –aware Routing Algorithm

In energy limited ad hoc networks, if the energy of some nodes is exhausted, networks could not carry out functions. Thus, effective routing to not make energy exhausted nodes should be developed. To prevent network disconnection, various effective routing algorithms considering energy remaining amount of each node or power consumption have been suggested. For energy efficient routing, network lifetime and network capacity are included in the valuation basis of network ability [10]. And network lifetime is defined as the time until the first energy exhausted node upon. Network lifetime is defined as the time that until the first node is occurred that energy exhausted and network capacity is defined as the total amount of successful transmission data. In ad hoc

networks, since the route towards the destination is various, we need some basis to select the best route. In this time, the basic standard is routing cost. In order to extend network lifetime and network capacity, some energy efficient routing algorithm used energy remaining as routing cost [4], [5], [10], [11].

These kinds of energy-efficient routing algorithms choose the route that is considered the cost which is decided based on remaining energy of each node, so it uses some node that has enough energy. At this time, various ways are used for the basis selecting route. MBCR(Minimum Battery Cost Routing) is the way to select the least expense route in side of energy amount contained in nodes and if the sum of remaining energy of all nodes in the route is bigger, the less cost is measured [11].

Like this, defining the sum of node cost as routing cost, MBCR puts the importance on the all course energy rather than the energy of each node. Also, MMBCR selects a path which is maximum node cost of path is minimum cost [5]. CMMBCR(Conditional Max-Min Battery Cost routing) uses the way to select the route which minimum energy consumption. And when the all nodes of path have more energy than regular standard, the optimum path can be used. So CMMBCR can consider remaining energy [11].

In case of on-demand type, routing cost exchange process is not performed after path routing process. So it is difficult to apply information about remaining energy of each node effectively. Consequently, PSR is developed that changes the selection of the route as per the ration of energy of each node [5]. PSR is an energy consumption aware routing method based on DSR which supplements some functions of selecting the route from the consideration of energy consumption and periodical changing of route. PSR enables to memory all the addresses of nodes which are routes that the RREQ packet passed through as per the DSR routing, as well as the ration of energy for each node.

where $C_i(t) = p_i\left(\frac{F_i}{R_i(t)}\right)^{\alpha}$ (1)

p_i : Transmit power of node *i*

F_i : Full-charge battery capacity of node *i*

R_i : Remaining battery capacity of node *i at time t*

α : A positive battery weight factor

$C(r,t) = \sum_{i \in r} C_i(t)$ (2)

Ci(t) Equation of 1, presents cost of using node i at current time and Pi presents amount of energy consumption when transmit. and Fi represents the initial energy, Ri(t) remarks remaining energy of node at current. C(r, t) of equation 1 expresses the expense of route at the sum of all node expense. The total routing expense of all routes based on sum of all each routing cost (2) and then one of route which is the least cost is selected.

It means PSR changes the route in order to prevent loss of energy which is usually occurred by using a specified node for long time. PSR restarts the path routing process when an error is caused on existing route, by sending RERR Packet. Otherwise the PSR has limitation that high-traffic of routing is additionally required in order to change and select the route periodically.

D. Multi-path Routing in Mobile Ad hoc Networks

The routing protocols, proposed previous section, for ad hoc networks are single path routing protocols. In single path routing, only a single path is used between a source node and a destination node. These routing protocols generally have problem that cannot maintain high efficiency in the networks which have frequent changing of topology of nodes.

However, multi-path routing consists of finding multiple routes between a source node and a destination node. Such a multi-path routing between a source node and a destination node pairs can be used to compensate for the dynamic and unpredictable nature of ad hoc networks. So that multi-paths can provide load balancing, fault-tolerance, and higher aggregated bandwidth [12]. This multi-path routing consists of three components: route discovery, route maintenance, and traffic allocation. Route discovery consists of finding multiple routes between a source node and destination node. Multi-path routing protocols can attempt to find node disjoint, link disjoint, or non-disjoint routes. Node disjoint routes have no nodes or links in common. Link disjoint routes have no links in common, but may have nodes in common. Non-disjoint routes may have lower aggregate resources than disjoint routes, because non-disjoint routes share links or nodes. Disjoint routes offer higher fault-tolerance. Route maintenance finds and repairs the broken paths. And the traffic allocation strategy is used to deal with how the data is distributed among the paths. Energy aware routing protocols, which reviewed previous, choose optimal single path based on routing cost. So, there is a limitation of using energy of nodes in path effectively.

EA-MPDSR, energy efficient protocol, has been proposed, that uses multiple paths to distribute traffics based on rate of each routing cost [1]. EA-MPDSR is multi-path routing based on on-demand DSR protocol. EA-MPDSR restricts the number of path within only two, because it considers problems which are packet reassembly and radio interference at destination node. In case that, the goal of this study is improving of the critical point of the EA-MPDSR. In other words, Proposed TP-MESR has focused on increasing number of path that used in one time.

III. Routing Algorithm Design Based on Design-Science Research Guidelines

In this section, TP-MESR protocol is proposed. And details about TP-MESR are suggested: TP-MESR process, proposed cost function. Also design science research guideline for systematic structure of research is explained in this section.

A. Design-Science Research Guidelines for TP-MESR-Protocol

In this study, we applied Hevener(2004)'s design science research guideline to propose TP-MESR protocol

systematically [13]. These design science research guidelines helps to explain a problem solving process systematically. Also it helps researchers and students to understand research easily. It consists of 7 guidelines: following explanation will show details. According to guideline, IS Research paper should be creative and useful for a specified problem domain. In other words, the relevance and importance of the problem should be demonstrated well in a research (guideline 1 and 2). That is, the study should be yield result for the specified problem. Also research paper must be demonstrated via well-executed evaluation methods and provide clear contribution in the areas of research (guideline 3 and 4). In this process, research should be conducted the rigorous methods (guideline 5). And design of research essentially has to have effective search process to discover an effective solution to a problem (guideline 6). Finally, the result of the research must be communicated effectively (guideline 7) both to a technical audience and to a manager.

Following Hevener, when the research satisfies the intent of each of the guideline, it can have contribution both practically and academically. In previous review, limitations of existing protocols are confirmed and the problems were chosen that studied in our research: guideline 2 was confirmed. From the following section, other guidelines are applied to explain the algorithm and to propose TP-MESR protocol effectively.

B. Proposed TP-MESR Protocol Algorithm

The purpose of TP-MESR is to maximize ability of multi-path routing than previous routing protocols in energy aware routing protocol. As mentioned section II-D, multi-path routing can provide load balancing, fault-tolerance, higher aggregated bandwidth. EA-MPDSR applied multi-path routing effectively, but the number of path to use at one time is limited due to packet reassembly overhead and radio interference in destination node (guideline 2). The number of path is related to effectiveness of multi-path routing.

Thus, this study focuses on increasing the number of path. The main issue of TP-MESR distributes data traffic by predicting it. TP-MESR is similar to the majority of energy-aware source routing. It consists of three components: route discovery, route maintenance, and traffic allocation. In this paper, cost function becomes a standard for choosing the path (guideline 1). This includes traffic allocation for multi-path such as EA-MPDSR. From following part, guideline 1 and 5 including design of model will be confirmed.

1. Route Discovery

Energy aware single-path routing protocols is structured as selecting optimal one path from multiple paths. For this, destination node establishes periodic time interval, when RREQ is received.

By contrast, TP-MESR acquires optimal multiple paths. For this, source node and destination node has multi-path table. The multiple paths received by the destination should check node-disjoint and cost level for adding to a multi-path table. Node-disjoint prevents increasing traffic load, because nodes are not shared between the paths. It is important to choose paths that are as independent as possible to ensure valid effects of traffic allocation.

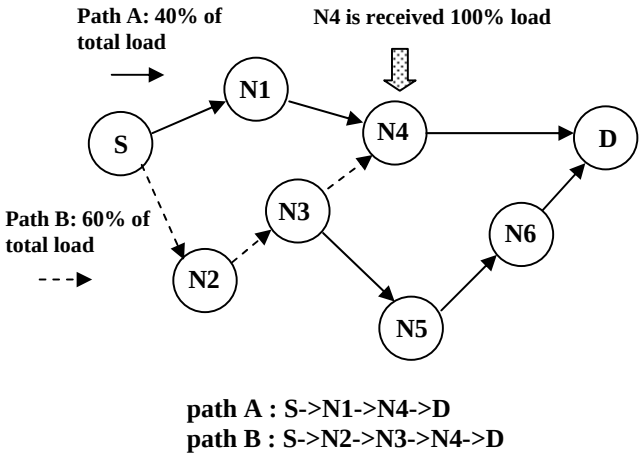

Fig. 2 Traffic Load of Paths Sharing Node

Cost level checks a validity of paths acquired.

After the condition of node-disjoint and cost level is applied, final paths which are selected are transmitted through RREP to the source node. Route discovery is finished by receiving RREP in the source node.

2. Route Maintenance

Route maintenance in TP-MESR is similar to DSR and PSR which are the representative source routing. The intermediate nodes send a RERR and inform not to use broken paths to the source node, when the energy of some nodes is depleted. The source node removes broken paths from multi-path table, when RERR arrives. So, the broken path would no longer be considered as load balancing. If multi-path table is empty, route discovery will restart automatically.

3. Cost Function

In TP-MESR, energy cost becomes standard for avoiding the route with nodes having the minimum energy among all nodes in all possible routes. Thereby, it results in fair use of the energy of each node. This concept of cost function was proposed in previous energy-aware routing protocol such as MMBCR (Min-Max Battery Cost Routing)[11]. The following cost function is summarized:

$$Cost(P) = \frac{1}{\min\left(e(N_0), e(N_1), e(N_2), \ldots, e(N_{i-2}), e(N_{i-1})\right), \forall N \in P}$$

Cost() : cost function to acquire the route cost
N : nodes of belong to path *P*
P : set of all nodes
e() : energy rating of nodes
i : sequence of all nodes from source node to destination node

The cost function is a reciprocal of minimum energy rating of

their nodes in the path. In this study, when the destination node received RREQ, cost function extracts proper paths by using time interval of arrived RREQ in route discovery. Thus, if the path is satisfied following condition, it will except from cost measurement.

Have cycle inside network topology

Go through too long hops at destination node

The path which is arrived at the time is applied to cost function. The advanced cost function exists, but this study does not focus on it. Furthermore, if the path does not make exception such as difference of relative length, in TP_MESR, the difference of energy efficiency is considered as relative factor by type of cost function.

4. Traffic Allocation through Traffic Prediction

In EA-MPDSR, the number of path is limited as two due to the problem of packet reassembly overhead and radio interference. Those problems are caused by using multiple paths simultaneously in parallel. This paper chose sequential transmission protocol for improving efficiency of multi-path and performed traffic prediction function. The source node accomplishes load balancing dynamically in real time environment. The following prediction function that calculates prediction value of traffic load is summarized:

$$P(N) = \frac{\alpha * R + \beta * S}{\delta(t)}$$

P() : Prediction Function

α, β : dependent constant about energy depletion in network environment, when data is transmitted and received

$\delta(t)$: applied time interval following network environment

The calculated value of this function is higher value, when traffic level is increased. The higher traffic makes high value of cost function. The higher traffic makes high value of cost function. In opposite conditions, it makes low value of cost function.

When $\delta(t)$ is finished, nodes transmit TPP(Traffic Prediction Packet) in the source node. TPP performs role to transmit calculated prediction value in prediction function. In prediction function, it is the most important to determine $\delta(t)$. If this value is too short, the transmission rating will be increased and almost a parallel packet transmission is performed. This problem is applied in EA-MPDSR. Furthermore, energy lost caused by TPP. Too long time interval reduces effectiveness of load balancing by multi-path. That is, there is no meaning to use multi-path routing.

IV. Simulations and Result Analysis

In this section, performance of TP-MESR is evaluated. So, conditions of simulation, environment conditions and results will be discussed. In section III, Guideline 1, 2 and 5 are confirmed. Design science research guideline is also one of methods for this study (Guideline 4, 5). From this part, Guideline 3 and 6 can be confirmed.

A. Simulation environment and Methodology

Network simulator II [14] have used in this study to evaluate efficiency of TE-MESR (guideline 6). And the default parameters that we used in simulations are summarized in Table II.

TABLE II.
SIMULATION ENVIRONMENT

Parameter	Set value
Size of area space	500 m2
Transmission range	radius 200m
Packet rate	1/0.1s
Initial retention energy quantity of all nodes	10000 (fixed)

In the condition above, we had arranged two different scenario which take the change in the number of starting point's nodes that originate total network node and traffic.

- fixing the number of total nodes, and adding on the numbers
- carrying out the positive opposite operation

Each fixed values are like this - total nodes are 50, and starting point's nodes are 10. All nodes constitute network topology randomly in the network situation. And, we had made all routing methods carrying the same traffics at the same time by making the starting point's node products the traffic in continuous phase from start till end.

B. Performance evaluation

The main point of TP-MESR is to improve efficiency of multi-path routing by using traffic prediction method. To estimate performance of TP-MESR, EA-MPDSR is chosen for comparison. Also, PSR is chosen for comparison to find out difference between single-path and multi-path routing.

The measured values from comparison mean network life time. The value of network life time means how long time the network maintains the networking. This value is obtained when the networking is stopped and end point of networking is defined as the point of the first energy exhaustion node comes up. Network life time for each simulation is used, the mean value of 5 times experimentation, in order to minimize the consequence of dynamic topology of nodes (guideline 3: well-designed method).

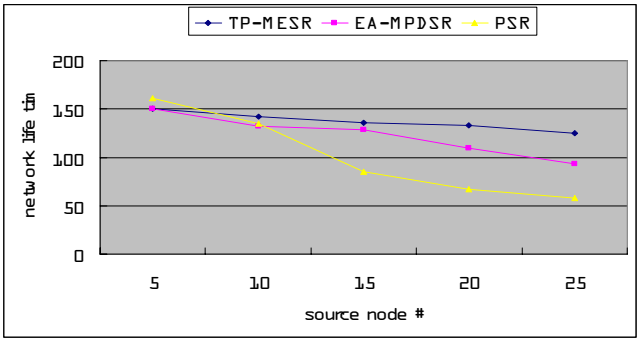

Fig. 3 Increasing Source Node Number in Fixed Total Node Number

In the first simulation, network lifetime is measured in conditions below:

- Total number of fixed nodes: 50 nodes
- The number of source nodes: regularly increase

The more Source node that causes traffic increases, the more traffic is produced. That is why all protocols are going down in the graph. In the simulation, TP-MESR shows the longest network life time: except the segment that is the number of source nodes are less than 5. Specially, When the number of source nodes are from 20 to 25 , TE-MESR outperforms EA-MPDSR by about 10% (10 sec) and when the number of source node are 25, it performs better than EA-MPDS by about 23% (26.12sec), (guideline 3). PSR shows best performance when the number of source nodes is less than 5, it means optimal single path routing is better in small network area. But when the number of source nodes is from10 to 20, its network life time is rapidly going down. It presents, single-path routing is not enough to solve the traffic loads.

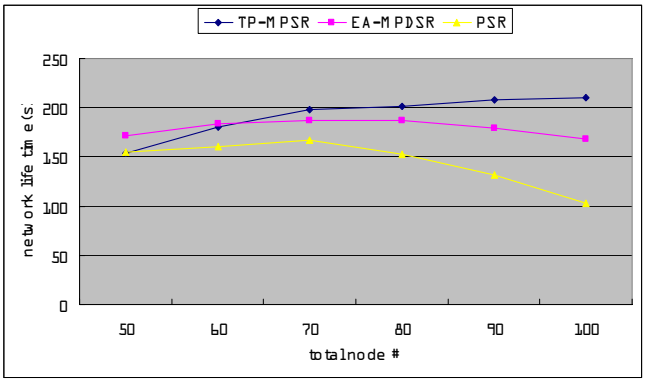

Fig. 4 Increasing Total Node Number in Fixed Source Node Number

In the second simulation, network lifetime is measured in conditions below:

- The number of source nodes: fixed
- Total number of nodes: regularly increase

The character of this simulation shows the efficiency related to energy consumption of protocols. EA-MPDSR shows best performance when total number of nodes are 50~60. EA-MPDSR uses only 2 paths but is best protocol for load balancing. In case of TP-MESR, it needs time to predict so it is not best protocol for load balancing. However, as the number of nodes increase gradually, the effect of the use of multi-path more than two gets result of continuous rising graph, and even rises until getting 100 nodes. While, in 2 multi-path of EA-MPDSR from 80 it start to decrease after increasing but not drastically. The reason why the graph does not increase or keep an original value, though the number of nodes, which are capable of energy increase, is the energy consumption, which result from RREQ broadcasting created during setting path increase. Energy consumption increases proportionate to increase of nodes because of adding the broadcasting cost of nodes. By using single-path, PSR is the highest traffic load because of modifying path frequently.

V. Conclusion

This paper studies routing protocol for using efficient energy in ad hoc networks which is operated as limited energy. First of all, this paper examines energy aware routing protocols that have been developed for ad hoc networks. Multi-path routing can provide load balancing, fault-tolerance, and higher aggregated bandwidth. In EA-MPDSR, the number of path is limited as two due to the problem of packet reassembly overhead and radio interference. Thus, avoiding the problems which were mentioned in advance, this paper studies solutions to get effect of multi-Path routing.

So, this paper suggests traffic prediction based on energy aware source routing using multi-path. The traffic prediction function informs the source node to traffic load that should be managed for a regular time. The source node can choose paths which transmit packet. This proposed routing protocol is named TP-MESR. It is implemented in network simulator (NS-2). As a result, TP-MESR out performs PSR and EA-MPDSR. Also, design science research guidelines which the Hevner(2004) suggests are applied to give a academic value and explain protocol systematically. Each guideline is confirmed in a study.

The limitations of this paper are as followed. Traffic prediction which is proposed in TP-MESR, causes lower performances than previous energy routing protocols, if time interval is too long or short. Thus, the definition of time interval is required. This kind of Time interval is influence by network environment that is an external factor of routing.

Accordingly, there needs more study for details. It would be quite helpful to apply to ad hoc networks for TP-MESR.

VI. Acknowledgment

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