# Comparative Study of SWST (Simple Weighted Spanning Tree) and EAST (Energy Aware Spanning Tree)

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**Abstract**

Wireless Sensors Networks (WSNs) are utilized in many diverse applications ranging from security, environmental monitoring, landslide detection, patient monitoring, reconnaissance operations, structural health monitoring and smart buildings. Since in many applications the WSN nodes are randomly deployed, WSNs need to be able to arrange and self-organize. Nodes in WSNs generally possess low or limited power resources such as batteries. Energy utilization thus is an important design consideration for WSN deployment. There have been many energy aware protocols proposed in the literature to increase the longevity of the network. Recently, two novel Connected Dominating Set (CDS) based topology construction (TC) protocols- SWST (Simple Weighted Spanning Tree) and EAST (Energy Aware Spanning Tree), have been proposed which aim to balance the load among the nodes of the network and thus to reduce the probability of dying for a particular node. The SWST and EAST protocols aim to reduce the number of broken links that may have been caused by a single node becoming dead or comatose in the communication backbone of the network. In this paper, a comparative study of the SWST and EAST algorithms is conducted to evaluate the performance of the two algorithms. From the MATLAB simulations it was observed that the EAST protocol generally performs better than the SWST algorithms in delivering messages to the sink node.

*Keywords*: SWST (Simple Weighted Spanning Tree), EAST (Energy Aware Spanning Tree), Connected Dominating Set, Topology Construction Protocol

## 1. Introduction

With the increase in Wireless Sensor Network (WSN) applications, improving and creating more energy efficient WSN topology control and construction protocols continues to be an open research topic.[1-9] WSNs do not have any fixed infrastructure and can form a network by themselves regardless of the manner of the deployment of the nodes. Sensor nodes facilitate monitoring a region and detecting an event of interest without the necessity of the presence of any human being reducing the risk for persons, such as for perimeter control and environmental measurements for monitoring possible natural disasters such as tsunamis, earthquakes and landslides. Also, commercial applications include examples such as the detection of faults in pipelines, buildings, bridges and other infrastructures. Tiny nodes can be used to create a wireless network which will be attached to the patient's body and collect real time medical data. In addition, these networks will play a vital role in merging real or physical world with the computer or virtual world in the near future.

Any wireless sensor network implementation involves the deployment of numerous sensor nodes, deployed randomly or with predetermined locations. Most sensor nodes possess a power source, processing capabilities, memory storage, a transceiver and a sensing device that measures events of interest as shown in Fig. 1.[4]

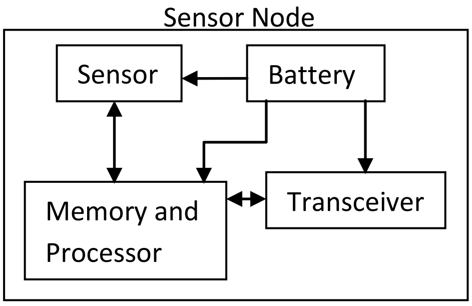


Fig. 1. Typical Sensor Node[4]

Many WSN protocol methods have been introduced in the literature to reduce energy consumption, improve WSN performance or increase network lifetime, such as found in Refs 1-9. In one example, Mitra and De Sarkar study an energy aware method.[6] Muni, Kandasamy and Chandrasekaran study a new partitioning scheme to distribute WSN loading.[7] Deshpande and Patil propose a cluster of cluster heads for organizing the WSN.[8]

Two novel Connected Dominating Set (CDS) based topology construction (TC) protocols- SWST (Simple Weighted Spanning Tree) and EAST (Energy Aware Spanning Tree), have been proposed which aim to balance the load among the nodes of the network and thus to reduce the probability of dying for a particular node.[1-3] In this paper, a comparative study of the SWST and EAST algorithms is conducted to evaluate the performance of the two algorithms.

The authors propose that the number of successful message deliveries should be the most significant metric to evaluate any topology protocol rather than the number of active or dead nodes or the total amount of the energy remaining in the network because the primary goal for a sensor network is to detect events and send them to the base station (BS) through the sink node. A WSN may have energy left in the network but if part of the communication backbone has ceased transmitting than an event can go unreported to the base station due to broken communication links. This basically means that the primary reason for the WSN, to send information on detected events, cannot be achieved. This was a primary reason to develop and analyze the proposed load balanced algorithms SWST and EAST.[1-3] These protocols generally reduce the load on a given node thereby extending the node's lifetime by moving the responsibility to other nodes with more energy during topology maintenance ensuring a more load balanced WSN.

Fig. 2 illustrates the periodic Topology Construction and Topology Maintenance exhibited in a WSN. In this paper, the SWST and the EAST algorithms are studied and compared. To evaluate the performance of the construction protocols, a simulator was created in Matlab. The rest of the paper is organized as follows: Section 2 discusses the SWST and EAST protocols, Section 3 presents the simulations and the conclusions are in the last section.

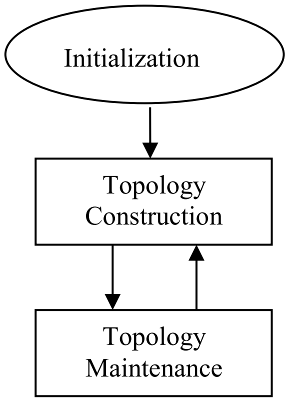


Fig. 2. The iterative execution of a topology control algorithm in a typical WSN

## 2. The SWST and EAST Topology Construction Protocols

In this section, the topology construction protocols under consideration- the SWST (Simple Weighted Spanning Tree) and the EAST (Energy Aware Spanning Tree) algorithms are discussed. The SWST protocol balances the energy consumption between the parent and children nodes. The EAST algorithm balances the load among the communication branches of the virtual communication backbone. The following figures Figs. 3., 4. and 5. briefly describe the EAST, EAST with neighborhood discovery and SWST protocols. Figs. 3 and 4 illustrate the EAST and SWST protocols which are based upon the detailed descriptions in Refs. 1-3. The following variables are defined for the EAST and SWST protocols.[1-3]

EAST

E(u)=remaining energy,
status(u)=either active, sleeping or comatose,
hop(u)=hop number,
OEM(u)=old energy metric,
NEW(u)=new energy metric,
NE(u)=set of NEWs of neighbor nodes,
PE(u)=set of NEWs of parent nodes,
P(u)=set of parent node IDs,
FP(u)=final parent node ID,
N(u)=set of neighbor node IDs,
tr(u)=transmission range.

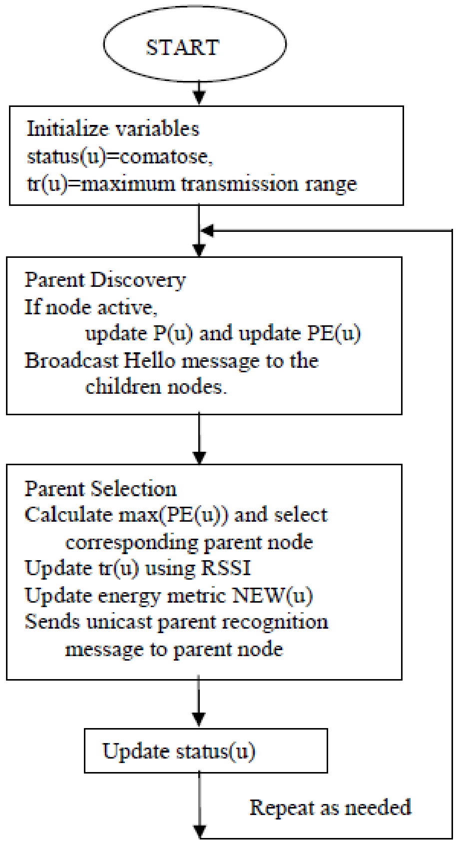


Fig. 3. EAST topology control algorithm

SWST

E(u)=remaining energy,
status(u)=either active, sleeping or comatose,
D(u)=set of distances between the current node and the sender nodes,
PE(u)=set of energy levels of the parent nodes,
P(u)=set of parent node IDs,
FP(u)=final parent node ID,
tr(u)=transmission range,
TEL=Threshold Energy Level.

Fig. 4 for the EAST Protocol with neighborhood discovery is based upon the detailed description in Refs. 1. and 3.

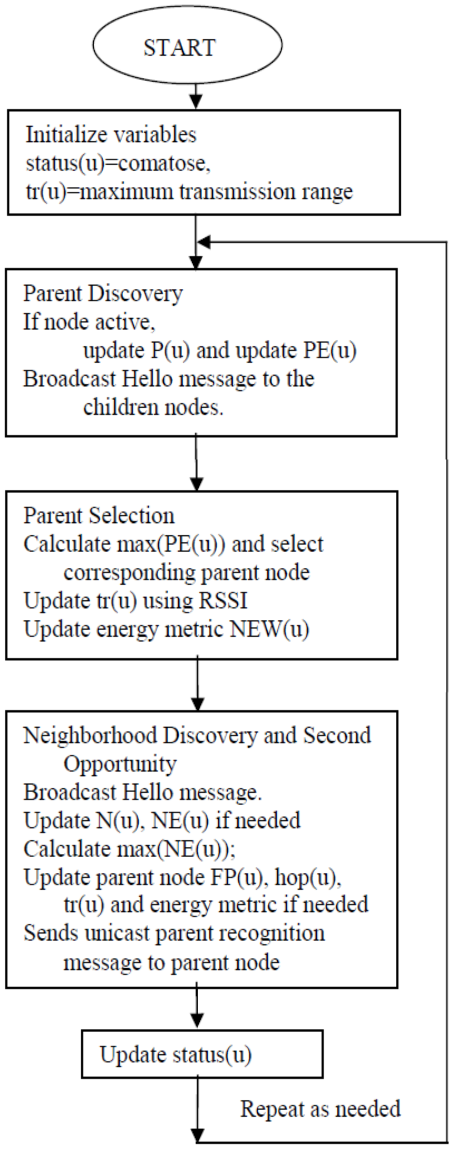


Fig. 4. EAST with neighborhood discovery topology control algorithm

Fig. 5 for the SWST Protocol is based upon the detailed description about the two EAST protocol and SWST algorithms found in Refs. 1.-3. The simulations and results are shown in the next section.

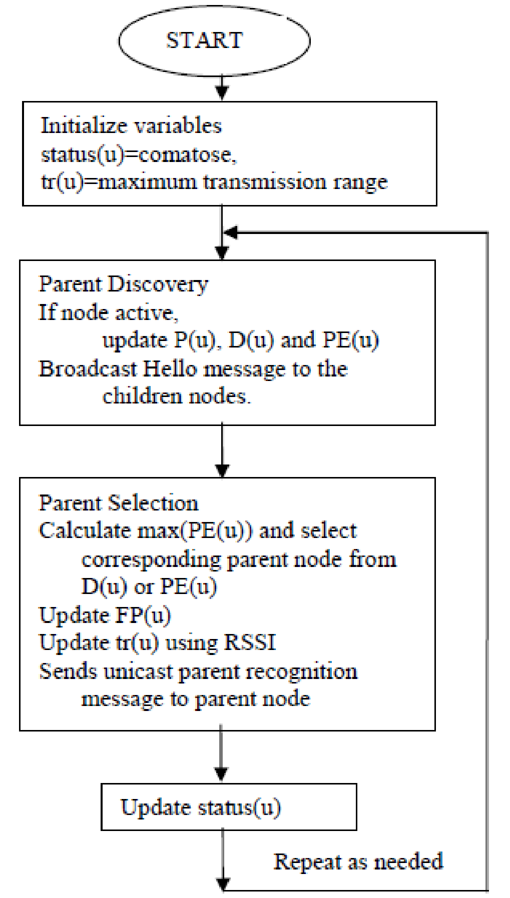


Fig. 5. SWST topology control algorithm

## 3. Simulations

The methodology to evaluate the algorithms adopted in this paper is taken from Refs. 1.-3. The assumptions are included here.[2]

Assumptions as found in Ref. 2.

1) Nodes are placed randomly in two dimensional Euclidian space.
2) Nodes exhibit perfect disk coverage.
3) Nodes exhibit same maximum transmission range and same sensing range.
4) All nodes are within the sink node's maximum transmission range.
5) Nodes do not possess information concerning their position, orientation and neighbors.
6) For simplicity, packets are assumed to not be lost in the Data Link layer.
7) Distance between two nodes is determined using Received Signal Strength Indicator (RSSI).
8) Network duty cycle = 100%.
9) Two or more simultaneous events in the network cannot occur, and rate of event occurrence is one event per second.[2]

**Node Energy Model**:[5,10] "Energy used during transmission and reception is:

$$E_t(k,r) = kE_{elec} + k\varepsilon r^2 \quad (1)$$
$$E_r\,(k) = kE_{elec} \quad (2)$$

where, $E_t(k,r)$ and $E_r(k)$ is the transmitting and receiving energy required for k bit of data, $E_{elec}$ is the energy needed to operate the transmitter radio, $\varepsilon$ is the energy consumption of the radio amplifier per unit area and r is the variable transmission range.[3]" The parameters for initializing the simulations are found in Table 1.

TABLE 1.[2,3]
SIMULATION PARAMETERS

| Parameters | Value |
|---|---|
| Deployment area | 1000m x 1000m |
| Event number | 2000 |
| Time of simulation | 2000 seconds |
| Number of events per unit time | 1 event/second |
| Initial energy of the sink node | 1000 |
| Maximum transmission range of the sink | 1000m |
| Topology Maintenance after the amount of time | 200 seconds |
| Energy consumed to transmit message for maximum range | 0.1 Joule |
| Energy consumed for listening in1 second | 0.01 Joule |

### 3.1 *Changing the node degree*

As one changes the maximum transmission range for a node, the node degree will increase. From Fig. 6, it can be observed that the EAST with neighborhood discovery algorithm outperforms the other two tested algorithms, under the assumptions and conditions used in the simulations, at successfully delivering messages to the sink node. As a consequence, EAST with neighborhood discovery possesses the largest number of dead nodes and least remaining energy in the network.

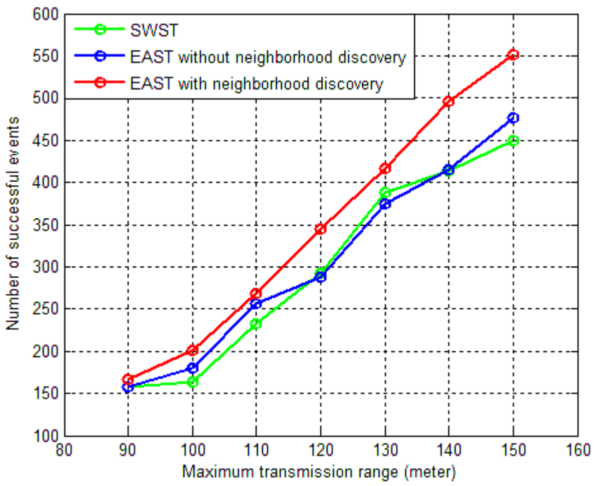


Fig. 6. Effect of the maximum transmission range over the number of successful events for SWST, EAST without neighborhood discovery and EAST with neighborhood discovery algorithms

### 3.2 *Changing the initial energy of each node*

If one changes the initial energy for each node in the network, one expects the network lifetime as well as the remaining network energy to increase. In addition, the number of dead nodes will decrease. As seen in Fig. 7, the node initial energy and number of successful events exhibit an almost linear relationship. Again the EAST algorithm with neighborhood discovery outperforms the other two tested algorithms.

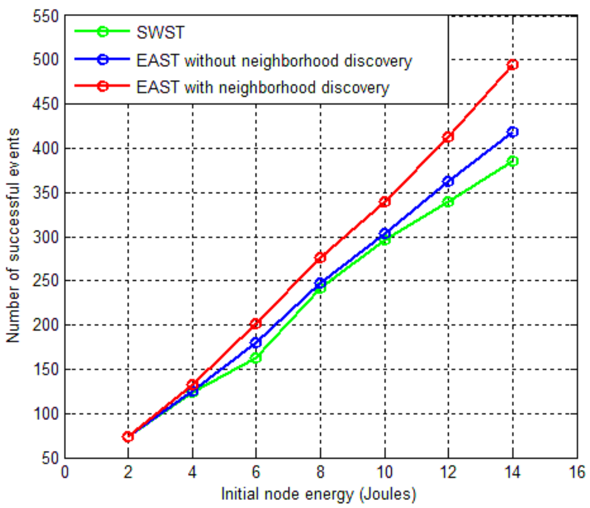


Fig. 7. Effect of the initial energy of each node over the number of successful events for SWST, EAST without neighborhood discovery and EAST with neighborhood discovery algorithms

### 3.3 *Changing the network density*

Fig. 8 depicts the effects as the network density is changed.

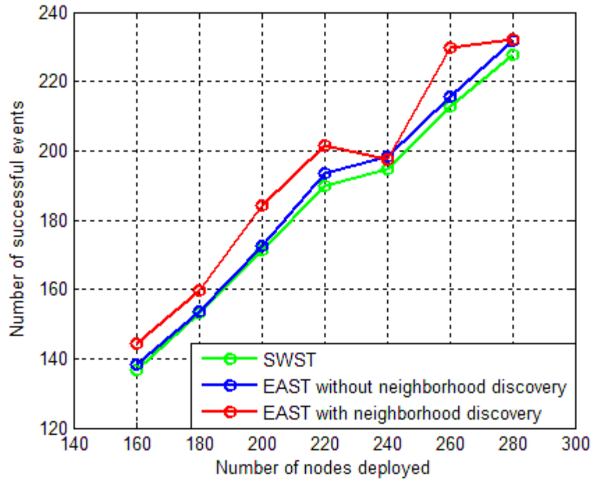


Fig. 8. Effect of the number of nodes deployed over the number of successful events for SWST, EAST without neighborhood discovery and EAST with neighborhood discovery algorithms[1]

“Changing the network density by deploying more nodes is an alternative way to increase the node degree of each node in the network. Consequently, each node has more options to choose its parent node and hence increases the longevity of the system and number of successful events. However, total number of dead nodes is high and the amount of remaining energy of the system is low for a densely deployed network. This is shown in Fig. 8.[2]” The relationships in Figs. 6-8 are fairly linear. Thus if one approximates each of the plots with a line, one can find the following equations to find the number of successful events as a function of transmission range, initial energy and number of nodes for the three tested algorithms:

SWST
# successful_events=4.83*transmission range-275
# successful_events=25.42*initial energy+24.17
# successful_events=0.77*number of nodes +13.33

EAST without neighborhood discovery
# successful_events=5.25*transmission range-312.5
# successful_events=28.75*initial energy+17.5
# successful_events=0.78*number of nodes +12.67

EAST with neighborhood discovery
# successful_events=6.33*transmission range-400
# successful_events=35.42*initial energy+4.17
# successful_events=0.79*number of nodes +18.33

Now one can plot a surface for the mean of the successful events as a function of the initial energy and transmission range, transmission range and number of nodes or initial energy and number of nodes. For the EAST with neighborhood discovery the following three surfaces can then be generated as seen in Figs. 9.-11.

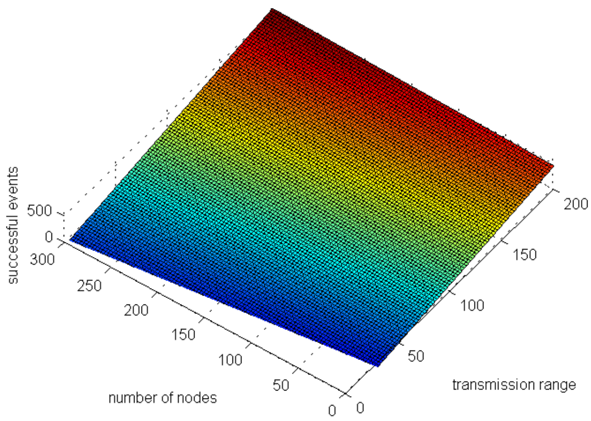


Fig. 9. Mean value for the number of successful events for EAST with neighborhood discovery as a function of the number of deployed nodes and the maximum transmission range

Similar plots can be obtained for the other algorithms. With the information in Figs. 9-11, one can obtain an estimate for the transmission range, number of nodes and node initial energy required to meet the application under the assumptions and parameters given in Section 3 and in Table 1.

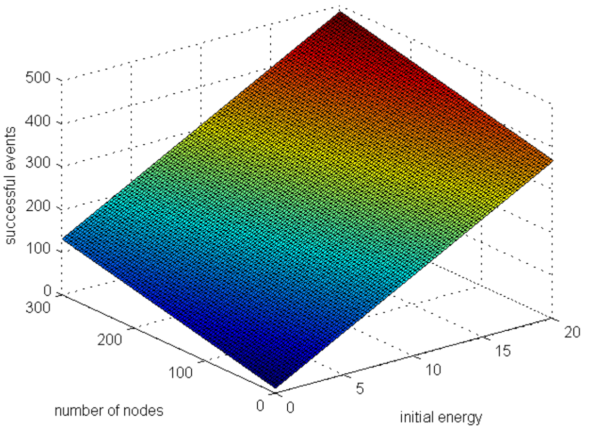


Fig. 10. Mean value for the number of successful events for EAST with neighborhood discovery as a function of the number of deployed nodes and the node initial energy

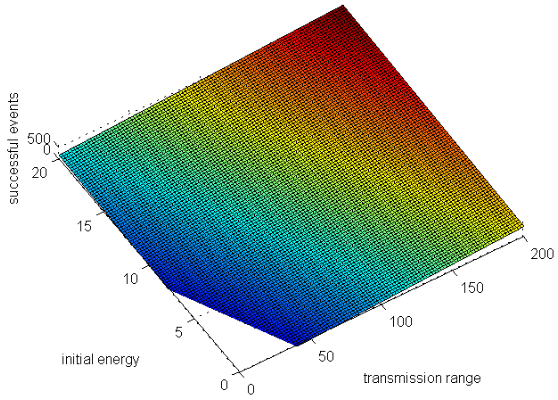


Fig. 11. Mean value for the number of successful events for EAST with neighborhood discovery as a function of the maximum transmission range and the node initial energy

The three planes shown in Figs. 9-11 assume that there must be a positive number of successful events. The linear approximations for the number of successful events however would not ensure positive values for the number of successful events. Thus as the number of successful events approach zero these approximations do not hold. Using the three figures one can determine operational points as a function of transmission range, initial energy and number of nodes. For example, in an application in which one needs at least 200 successful events given an initial energy of 6J, Fig. 12 implies that a minimum transmission range of at least 102m would be required with approximately 210-230 nodes (see Figs. 12 and 13) to result in at least 200 successful events when one examines the next two Figs. 13. and 14.

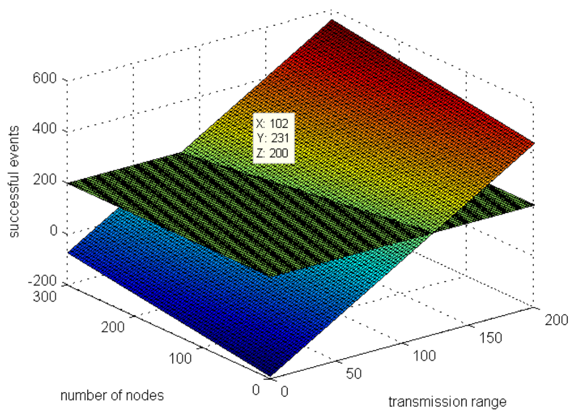


Fig. 12. Mean value for the number of successful events for EAST with neighborhood discovery as a function of the number of deployed nodes and the maximum transmission range with an intersecting plane with the value 200 successful events

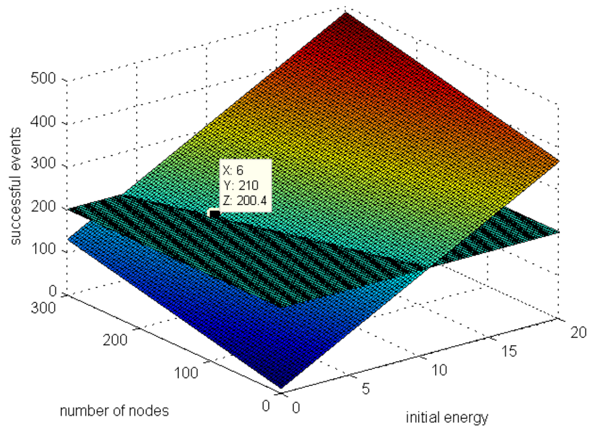


Fig. 13. Mean value for the number of successful events for EAST with neighborhood discovery as a function of the number of deployed nodes and the node initial energy with an intersecting plane with the value 200 successful events

After looking at Fig. 13, one needs at least 6J initial energy given 210 nodes to obtain at least 200 successful events. In Fig. 14 given 6J initial energy, one needs a transmission range of at least 100 m to obtain at least 220 successful events.

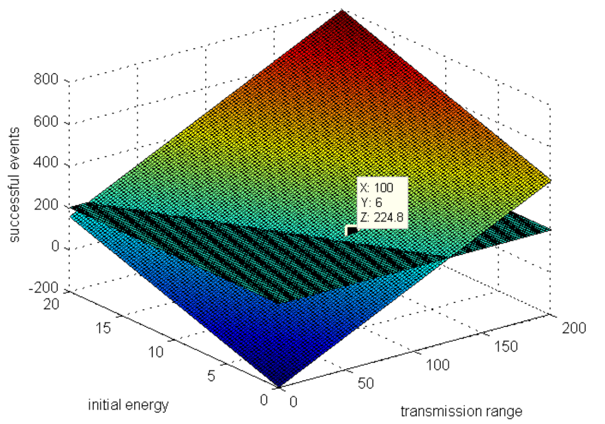


Fig. 14. Mean value for the number of successful events for EAST with neighborhood discovery as a function of the maximum transmission range and the node initial energy with an intersecting plane with the value 200 successful events

These numbers are consistent with Figs. 6-8. From these Figs. one determines that the number of successful events would be approximately 180-200. As the planes were made from linear models using mean values, one expects some deviations in the expected numbers of successful events. This information though could be utilized to obtain regions of interest for testing the protocols given operational requirements such as required nodes, transmission ranges, and initial energy values.

## 4. Conclusions

From the simulations it can be seen that in each scenario considered in this paper, the EAST algorithm with neighborhood discovery performs best among the three protocols. Although the simulation results proved the efficiency of the algorithm in load balancing, there are further areas to investigate concerning the performance of the protocol, for instance, in terms of message complexity.

The linear approximations for the number of successful events however would not ensure positive values for the number of successful events. Thus as the number of successful events approach zero these approximations do not hold. A nonlinear model would increase the useful range of the model for obtaining approximate values of required nodes, transmission ranges, and initial energy values to achieve a given number of successful events.

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