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Optimized Load Balanced Routing Protocol for a MIMO based Wireless Sensor Network

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Abstract: Wireless sensor networks consist of densely populated nodes with sensing, low computational and wireless communications capabilities. Many routing, power management and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. Routing protocols in WSNs might differ depending on the application and network architecture. WSN routing protocols are generally designed to account for a single sink and WSN multicast protocols optimize communication from a single source. In this study, a new routing protocol is developed to implement MIMO (Multiple Input and Multiple Outputs) communication where multiple sources report their data to multiple sinks. The aim is to increase network lifetime, by implementing on an energy efficient routing protocol which minimizes the number of nodes involved in routing and balances their forwarding load. The lifetime of the network was analyzed by implementing single sink and multi sink routing techniques. The optimal route path between multiple sources to multiple sink based on the link quality of the selected paths was determined with TinyOS test bed using Iris Motes.

Key words: Wireless Sensor Network (WSN), routing algorithm, MIMO, throughput, energy evaluation, quality

INTRODUCTION

Wireless Sensor Networks (WSNs) are composed of a large number of sensor nodes used to monitor an area of interest. This type of network has become popular due to its applicability which includes several areas such as environmental, health industrial, domestic, agricultural, meteorological, spatial and military. Routing in WSNs is very challenging due to the inherent characteristics that distinguish these networks from other wireless networks like mobile ad hoc networks or cellular networks. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network. In general, routing in WSNs can be divided into flat-based routing, hierarchical-based routing and location-based routing depending on the network structure. In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, nodes will play different roles in the network. In location-based routing, sensor node's positions are exploited to route data in the network (Fig. 1).

A routing protocol is considered adaptive if certain system parameters can be controlled in order to adapt to current network conditions and available energy levels. Furthermore, these protocols can be classified into multipath, query and negotiation-based QoS or coherent-based routing techniques depending on the protocol operation. In addition, routing protocols can be classified into three categories, proactive, reactive and hybrid, depending on how the source finds a route to the destination (Fig. 1).

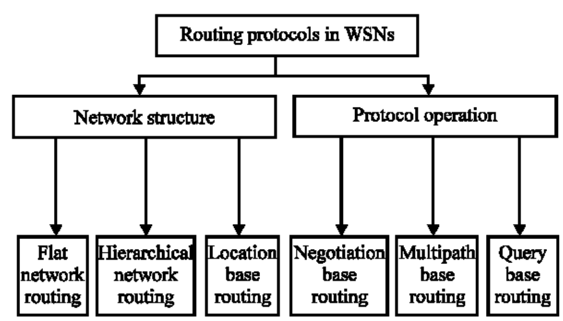

Fig. 1: Routing protocols in WSNs: a taxonomy

In proactive protocols, all routes are computed before they are really needed while in reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two ideas. When sensor nodes are static, it is preferable to have table-driven routing protocols rather than reactive protocols. A significant amount of energy is used in route discovery and setup of reactive protocols. Another class of routing protocols is called cooperative. In cooperative routing, nodes send

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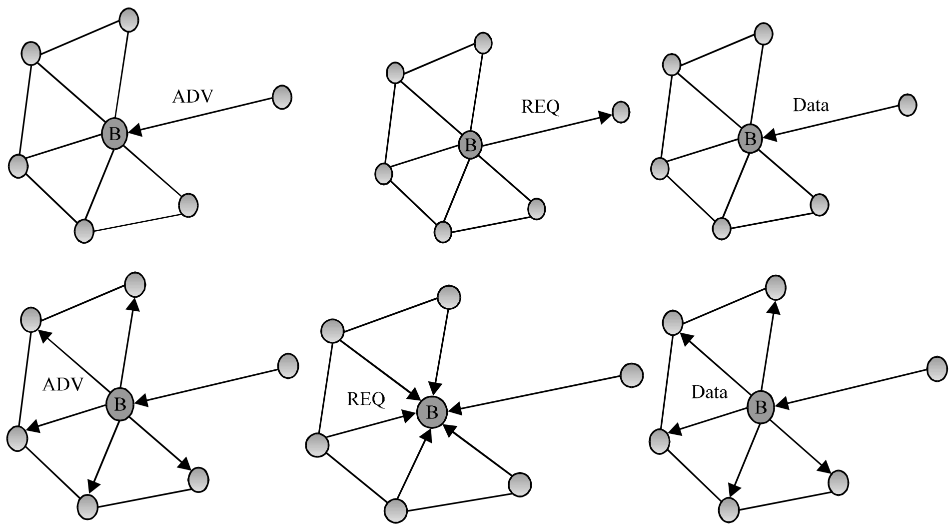


Fig. 2: SPIN protocol

data to a central node where data can be aggregated and may be subject to further processing, hence reducing route cost in terms of energy use. Routing metrics are a property of a route in wireless sensor networking, consisting of any value used by routing algorithms to determine whether one route should perform better than another. The routing table stores only the best possible routes while link-state or topological databases may store all other information as well. For example, Routing Information Protocol (RIP) uses hop count (number of hops) to determine the best possible route. A metric include: number of hops (hop count), it refers to the number of routers through which data must pass between source and destination, packet loss (router congestion/conditions), latency (delay), latency is a measure of time delay experienced in a system, path reliability, an indication of how reliable is the end-to end communication from neighbor n to sink s, path bandwidth, it's a measure of available or consumed data communication resources expressed in bits/second or multiples of it (kilobits/s, megabits/s, etc.). Bandwidth refers to analog signal bandwidth measured in hertz, Load, the load average represents the average sensor load over a period of time.

Routing algorithms: The underlying network structure can play a significant role in the operation of the routing protocol in WSNs.

Sensor protocols for information via. negotiation: Sensor Protocols for Information via. Negotiation (SPIN) is an adaptive protocol that disseminates all the information at each node to every node in the network, assuming that all nodes in the network are potential base station (Geetu, 2012). This enables a user to query any node and get the required information immediately. These protocols make use of the property that nodes in close proximity have similar data and hence, there is a need to only distribute the data other nodes do not posses. The SPIN family of protocols uses data negotiation and resource-adaptive algorithms. Nodes running SPIN assign a high-level name to completely describe their collected data (called meta-data) and perform metadata negotiations before any data is transmitted.

SPIN is a three stage protocol as sensor nodes use three types of messages, ADV, REQ and DATA to communicate. The steps involved in SPIN protocol are shown in Fig. 2. ADV is used to advertise new data, REQ to request data and DATA is the actual message itself. The protocol starts when a SPIN node obtains new data it is willing to share. The protocol broadcasts an ADV message containing metadata. If a neighbor is interested in the data, it sends a REQ message for the DATA and the DATA is sent to this neighbor node. The neighbor sensor node, then repeats this process with its neighbors. As a result, the entire sensor area will receive a copy of the data. SPIN's meta-data negotiation solves the classic problems of flooding, thus achieving energy efficiency.

Directed diffusion: Intanagonwiwat *et al.* (2003) proposes a popular data aggregation paradigm for WSNs called directed diffusion. Directed diffusion is Data-Centric (DC) and application-aware paradigm that all data generated by sensor nodes are named by attribute value pairs. The main idea of the DC paradigm is to combine the data coming from different sources en route (in network aggregation) by eliminating redundancy, minimizing the number of transmissions, thus saving network energy and prolonging its lifetime. Figure 3 shows the steps followed in interest diffusion in

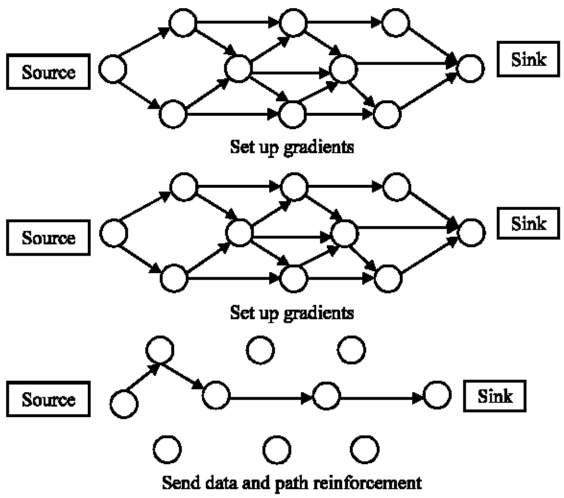


Fig. 3: Direct diffusion in a sensor network

a sensor network. Unlike traditional end-to-end routing, DC routing finds routes from multiple sources to a single destination that allows in-network consolidation of redundant data.

Energy aware routing: The objective of the energy aware routing protocol, a destination-initiated reactive protocol is to increase the network lifetime (Wang *et al*., 2010). Although, this protocol is similar to directed diffusion, it differs in the sense that it maintains a set of paths instead of maintaining or enforcing one optimal path at higher rates. These paths are maintained and chosen by means of a certain probability. The value of this probability depends on how low the energy consumption is that each path can achieve. By having paths chosen at different times, the energy of any single path will not deplete quickly. This can achieve longer network lifetime as energy is dissipated more equally among all nodes. Network survivability is the main metric of this protocol. The protocol assumes that each node is addressable through class-based addressing that includes the locations and types of the nodes. The protocol initiates a connection through localized flooding which is used to discover all routes between a source/destination pair and their costs, thus, building up the routing tables. High cost paths are discarded and a forwarding table is built by choosing neighboring nodes in a manner that is proportional to their cost. Then, forwarding tables are used to send data to the destination with a probability inversely proportional to the node cost. Localized flooding is performed by the destination node to keep the paths alive. Compared to directed diffusion, this protocol provides an overall improvement of 21.5% energy savings and a 44% increase in network lifetime. However, the approach requires gathering location information and setting up the addressing mechanism for the nodes which complicate route setup compared to direct diffusion.

LEACH protocol: Geetu (2012) introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster-based protocol which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as Cluster Heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. In LEACH, the CH nodes compress data arriving from nodes that belong to the respective cluster and send an aggregated packet to the BS in order to reduce the amount of information that must be transmitted to the BS. LEACH uses a TDMA/Code-Division Multiple Access (CDMA) MAC to reduce intercluster and intracluster collisions. However, data collection is centralized and performed periodically. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network.

MATERIALS AND METHODS

Proposed routing approach: Wireless sensor networks consist of densely populated nodes with sensing, low computational and wireless communications capabilities. Many routing, power management and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. Routing protocols in WSNs might differ depending on the application and network architecture. WSN routing protocols are generally designed to account for a single sink and WSN multicast protocols optimize communication from a single source. In this study, a new routing protocol is developed to implement MIMO (Multiple Input and Multiple Outputs) communication (Mottola and Picco, 2011) where multiple sources report their data to multiple sinks. The aim is to increase network lifetime, by implementing on an energy efficient routing protocol which minimizes the number of nodes involved in routing and balances their forwarding load. Existing WSN routing protocols are ill-suited to the scenarios above, as they focus on a single sink or source. This leads to inefficient communication, reducing the overall network lifetime. For instance, most protocols rely on a sink-routed routing tree (Yacoab, 2011) and the sink flooding a message that establishes a reverse path from every node to the sink. However, Fig. 4a shows the node A send the data to both sinks C and D whereas B only send to C. This may lead sources (e.g., A) to duplicate data and may increase the nodes involved, ultimately reducing the overall network lifetime.

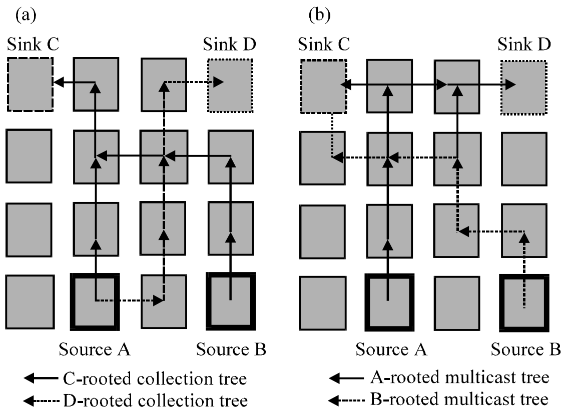


Fig. 4: a, b) A sample multisource to multisink scenario

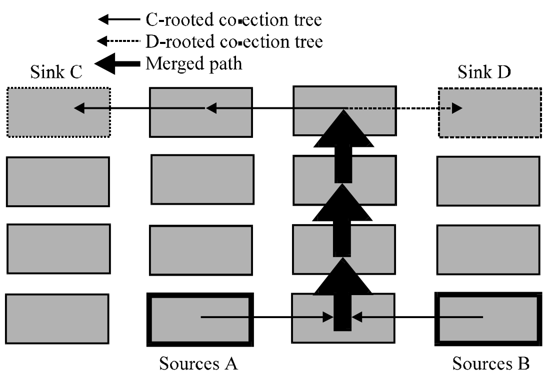


Fig. 5: Optimized path to balance the load

When separate multicast trees are used for many-to-many communication, they are affected by problems similar to collection protocols as shown in Fig. 4b. Multicast protocols minimize a given metric computed on a per-source basis, e.g., the number of links to reach the target sinks. As sources are not aware of each other, this approach cannot optimize the routing among intermediate nodes. Moreover, aggregation mechanisms lose their effectiveness, precisely because readings from different sources (e.g., A and B) can be combined only very late along their path to the sinks (Lo *et al*., 2010). The proposed protocol overcomes the drawbacks of independently built trees by reusing routing paths across multiple trees. This leads to significant improvements when traffic flows simultaneously from different sources to different sinks as illustrated in Fig. 5. This scheme reduces the number of nodes involved in routing in this example from 13 and 11 in Fig. 4a and b, to 9 in Fig. 5. In general, minimizing the number of nodes involved in routing enables a decrease in the amount of redundant information flowing in the network as data are duplicated only if and when strictly necessary, therefore increasing the system lifetime. As energy is progressively consumed in the configuration of Fig. 5, there are the two paths which are merged on different node to balance the load (Lo *et al*., 2010).

In general, minimizing the number of nodes involved in routing enables (Lo *et al*., 2010): a decrease in the amount of redundant information flowing in the network, as data are duplicated only if and when strictly necessary, therefore increasing the system lifetime, a reduced contention on the wireless medium and packet collisions, therefore increasing the reliability of transmissions and an increase in the beneficial impact of aggregation as readings can be combined much earlier, further reducing the net amount of data being funneled.

Network system model: The network system model a WSN as a directed graph where N is composed of the WSN nodes and A is obtained by setting an arc (i, j) between nodes i and j when the latter is within communication range of the former. Without loss of generality, we assume a commodity to flow from a single origin to a single destination. Since, commodities flowing from the same origin (source) to the same destination (sink) follow the same route, we can state a one-to-one mapping between the route connecting any source-sink pair <i(k), j(k)> and any commodity k (Feng and Heinzelman, 2009). The message routing r is captured with a set of decision variables:

$$r^k_{i,j} = \begin{cases} 1, & \text{if the route for source-sink pair k contains arc (i, j),} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

To minimize nodes involved, nodes along routes serving other source-sink pairs are reused that is nodes for which the cost ui is already paid. A directed graph (e.g., representing a transportation network) with node set N is considered and arc set A and a set of commodities C (e.g., goods). The goal is to route each commodity k∈C from a set of origins O (k)∈N to a set of destinations D (k)∈N by minimizing a given metric. Therefore, in the model we take the number of nodes (instead of links) participating in routing as the main metric. We capture the fact that node i is involved in at least one source-sink route as our objective function as:

$$\text{Nodes involved}\,(C,\ A) = \sum\nolimits_{i \in N} u_i \quad (2)$$

The objective is to identify the optimal set of routes to deliver messages from sources to sinks. Formally, we

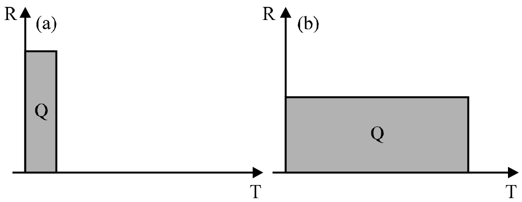


Fig. 6: Interplay between routing quality and expected lifetime: a) Neighbor n1: high routing quality and short lifetime and b) Neighbor n2: medium routing quality and long lifetime

are to find the value assignmen of $r^{k}_{i,j} \forall(i, j) \in A \forall(k) \in C$ such that nodes involved (C, A) is minimum. The optimal solution to this problem can be derived using mathematical programming techniques by specifying proper constraints (Jung *et al*., 2009). A value assignment $\forall(i, j) \in A$ to these variables represents the route followed by messages from source i(k) to sink j(k). The routing quality R(n, s) is concerned purely with the optimization of source-sink paths. T(n) is an estimate of the expected lifetime of n. Q(n) (Wang *et al*., 2008) is a measure of how long a neighbor n can provide a given routing quality toward a sink s:

$$Q(n, s) = R(n, s).T(n) \quad (3)$$

Based on information in the header, each node maintains, for every neighbor n and sink s, a value denoting the quality of n as a parent toward s. In principle, the routing quality R(n, s) can be defined in terms of various quantities. In this research, we consider the following ones.

Reliability (n, s) an indication of how reliable is the end-to-end communication from neighbor n to sink s. Paths (n), the number of source-sink paths passing through a neighbor n, sinks (n), the number of sinks n is currently sending data to.

Routing quality R alone, as illustrated in Fig. 6. However, the expected lifetime T of n1 is small is shown in Fig. 6a. Routing through n1 may deplete its battery, possibly disrupting connectivity. Figure 6b shows T of n2 has lower routing quality but longer expected lifetime (Fariborzi and Moghavvemi, 2009). The metric Q is used at each node to adapt the source sink paths by replacing the neighbor n serving as parent toward sink s with the maximum quality Q. As the new parent performs routing, its expected lifetime T(n, s) decreases, along with Q(n, s) and the child node finds another neighbor n0 with higher Q for sink s.

RESULTS AND DISCUSSION

Performance analysis: The simulations are carried out in MATLAB. The 100 sensor nodes are randomly deployed in a topographical of dimension 300×300 m (Dutta *et al*., 2008). The topographical area has the sensed transmission limit of 30 m. There is only one data sink which located at (90, 90 m) in the case of static sink and sink travelling diagonally across the specified dimension in the case of mobile sink. All sensor nodes have the same initial energy of 0.5 J. The proposed method uses the Friss free space radio model for its simulation. Simulations are done using the values 50 nJ/bit and 100 pJ/bit/m^2 for and respectively.

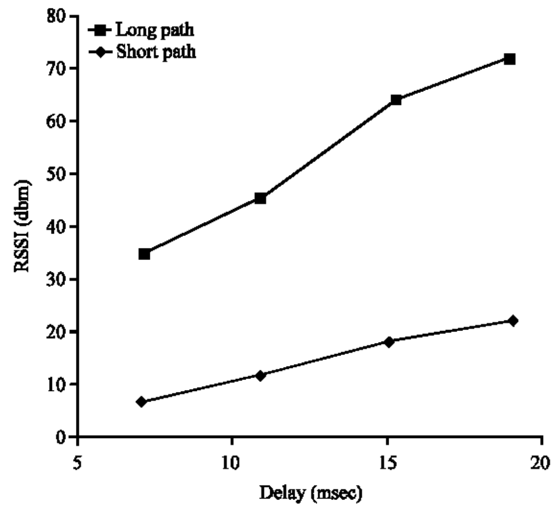


Fig. 7: The graph depicting the time delay vs. RSSI value

The routing quality can be analyzed by the performance of time delay and received signal strength. In this graph X-axis displays the time delay in milliseconds and Y-axis displays the received signal strength indicator in decibel meter. It shows the comparison of routing quality between short and long path. In case of shortest path, the value of delay decreases with decreasing RSSI and in the case of longest path, the value of delay increases with increasing RSSI (Fig. 7).

Figure 8 represents the options used in multi-hop routing topology and obtained the simulation of two paths. One as a busy path, though this path available is not going to be used. Otherone as a free path, let data jump through free path and reach the base station.

Multiple sources communicating to single sink: Figure 8 shows that the multi source takes the same path to reach the single sink. From the Fig. 8, it is observed that there is congestion near node 4 due to merging of multiple paths taken by the multiple sources to reach the single sink. This will invoke certain delay and decrease in network lifetime.

Figure 9 shows the graph which depicts the network lifetime between single sink with multiple sinks. From this

XSniffer 1.0.3

ElapsedTime	msec	Addr	RF	Type	Grp	Len	Src	Orgn	SeqNo	Hops	AppId
0:12:00	484	Base	45	DatUpAck	125	27	12	12	7604	1	51
0:12:00	484	12	24	AckDwn	125	10	0	12	7605	1	51
0:12:00	796	14	27	DatUpAck	125	27	25	25	1071	2	51
0:12:00	796	14	27	Rte	125	27	25	25	1071	2	51
0:12:00	796	Base	42	DatUpAck	125	27	0	5	7686	1	51
0:12:00	796	13	24	AckDwn	125	10	0	0	7607	1	51
0:12:00	796	Base	17	DatUpAck	125	27	13	0	7687	1	51
0:12:11	562	6	28	AckDwn	125	10	0	5	7688	1	51
0:12:11	562	6	22	Rte	125	10	5	5	2602	2	51
0:12:11	562	Base	36	DatUp	125	27	6	6	1247	1	51
0:12:11	875	Base	36	DatUpAck	125	27	14	14	1554	1	51
0:12:11	875	14	26	AckDwn	125	10	0	14	7689	2	51
0:12:11	937	6	30	DatUpAck	125	27	0	5	1896	2	51
0:12:30	550	6	24	AckDwn	125	10	5	5	7609	1	51
0:12:30	864	Base	27	DatUpAck	125	27	6	6	1082	2	51
0:12:30	864	14	27	Rte	125	27	25	25	1082	2	51
0:12:30	660	Base	42	DatUpAck	125	27	14	25	7690	1	51
0:12:30	660	13	24	AckDwn	125	10	0	0	7691	1	51

Fig. 8: Routing messages of shortest path 1 and 2

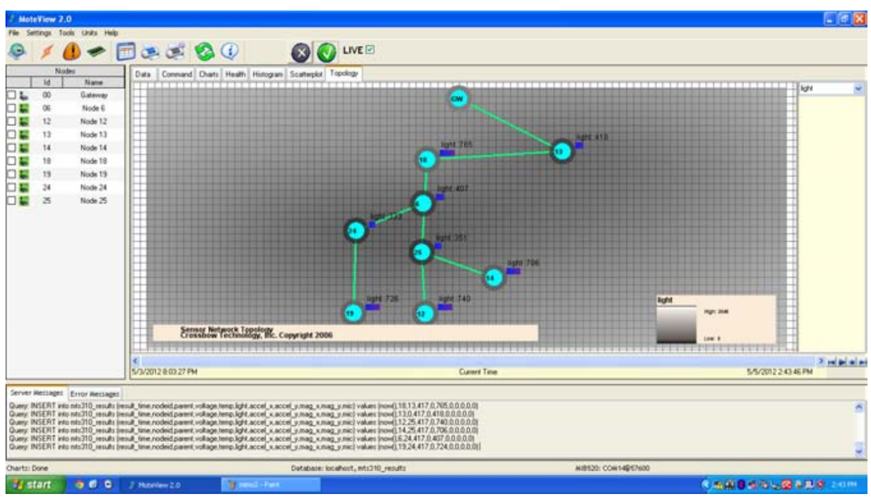


Fig. 9: Multi sources reporting to single sink

it is observed that the overall network lifetime decreases with multiple sources reporting to single sink with certain delay and in the case of multiple sources reporting to multiple sinks the network lifetime increases with scheduled time.

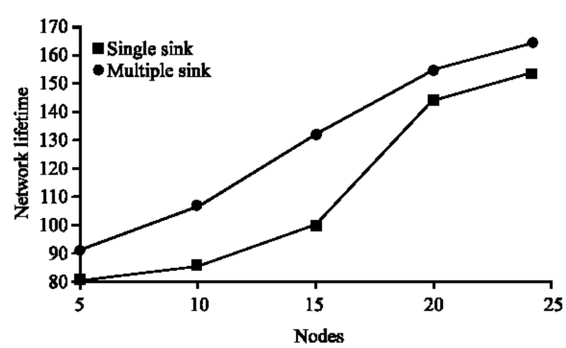
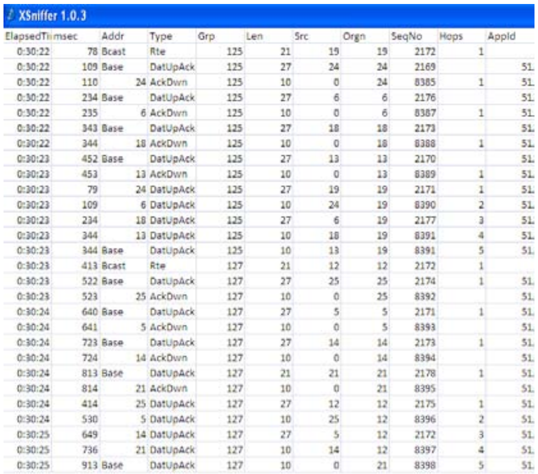


Fig. 10: Network lifetime with single sink and multiple sinks

Multiple inputs and multiple outputs: Figure 10 and 11 show the routing path in MIMO causes data from different sources travel together as early as possible (Xie and Kumar, 2007). It can be claimed that the path is always equitravelled distance. Even for any retransmission causes (in case of routing error or path failure) the alternate path can also be equal number of hops which increasing the network lifetime. Form this we can prove that the routing path 1 consists of 5 nodes (e.g., 6, 13, 18, 19, 24) having equal hops count send data packets to basestation 1 which is having their group ID as 125. And also the alternate routing path 2 consists


XSniffer 1.0.3

ElapsedTi	msec	Addr	Type	Grp	Len	Src	Orgn	SeqNo	Hops	AppId
0:30:22	78	Bcast	Rte	125	21	19	19	2172	1	
0:30:22	109	Base	DatUpAck	125	27	24	24	2169		51.
0:30:22	110	24	AckDwn	125	10	0	24	8385	1	51.
0:30:22	234	Base	DatUpAck	125	27	6	6	2176		51.
0:30:22	235	6	AckDwn	125	10	0	6	8387	1	51.
0:30:22	343	Base	DatUpAck	125	27	18	18	2173		51.
0:30:22	344	18	AckDwn	125	10	0	18	8388	1	51.
0:30:23	452	Base	DatUpAck	125	27	13	13	2170		51.
0:30:23	453	13	AckDwn	125	10	0	13	8389	1	51.
0:30:23	79	24	DatUpAck	125	27	19	19	2171	1	51.
0:30:23	109	6	DatUpAck	125	10	24	19	8390	2	51.
0:30:23	234	18	DatUpAck	125	27	6	19	2177	3	51.
0:30:23	344	13	DatUpAck	125	10	18	19	8391	4	51.
0:30:23	344	Base	DatUpAck	125	10	13	19	8391	5	51.
0:30:23	413	Bcast	Rte	127	21	12	12	2172	1	
0:30:23	522	Base	DatUpAck	127	27	25	25	2174	1	51.
0:30:23	523	25	AckDwn	127	10	0	25	8392		51.
0:30:24	640	Base	DatUpAck	127	27	5	5	2171	1	51.
0:30:24	641	5	AckDwn	127	10	0	5	8393		51.
0:30:24	723	Base	DatUpAck	127	27	14	14	2173	1	51.
0:30:24	724	14	AckDwn	127	10	0	14	8394		51.
0:30:24	813	Base	DatUpAck	127	21	21	21	2178	1	51.
0:30:24	814	21	AckDwn	127	10	0	21	8395		51.
0:30:24	414	25	DatUpAck	127	27	12	12	2175	1	51.
0:30:24	530	5	DatUpAck	127	10	25	12	8396	2	51.
0:30:25	649	14	DatUpAck	127	27	5	12	2172	3	51.
0:30:25	736	21	DatUpAck	127	10	14	12	8397	4	51.
0:30:25	913	Base	DatUpAck	127	10	0	21	8398	5	51.

Fig. 11: Routing paths of two sources and two sinks

of different set of equal nodes (e.g., 5, 12, 14, 21, 25) send data packets to basestation 2 which is having their group ID as 127 specified in the Xsniffer data output (Cao *et al*., 2007). This amplifies the beneficial effect of equal number of hops count in network, further reducing the amount of data flowing in the network.

CONCLUSION

The proposed method was simulated using MATLAB and the performance was analysed. The lifetime of network was analyzed by implementing single sink and multi sink routing techniques. The optimal route path between multiple sources to multiple sink based on the link quality of the selected paths was determined with TinyOS test bed using Iris motes. Temperature and light sensors was measured and monitored through Crossbow Sensor Kit by using Mote View and MoteConfig environment. The proposed routing algorithm was compared with standard routing protocol and observed increase in network lifetime.

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