CHAPTER 4

OPTIMIZED MULTIPATH ROUTING FOR BALANCED LOAD DISTRIBUTION (OMR-BLD) PROTOCOL USING MODIFIED INTELLIGENT WATER DROP (MIWD) ALGORITHM

4.1. INTRODUCTION

Wireless sensor network (WSN) is a collection of a large number of nodes deployed with processor, sensor, power source such as battery and transceiver with radio for communication as discussed by Yick et al **(**2008) and Radi et al (2012). These small, smart nodes of low cost sensing and computing devices open up new vistas for observing and monitoring physical phenomenon. WSNs are used for distributed and cooperative sensing of physical phenomena and events of interest. Sensor nodes communicate the occurrence of an event, which means the occurrence of any abnormality in the electrical system, to a sink node. Sink node then transmits the data through suitable communication protocols to the user or Base Station (BS). The entire area covered by the collection of sensor nodes is called a sensor network field. Power consumption happens in a node when there is a need to find the data transmission route, transmits data, acknowledges the requests from other nodes and processes data using complex algorithms etc. Developing energy-efficient protocols is critical for Wireless Sensor Networks (WSNs) because of the constraints on the sensor nodes' energy. The routing protocol should be able to optimize the power utilization during path finding and during transmission of data to the BS or coordinator.

The requirement for a wide variety of network services has been the major powerful strength for improvement and growth of various networking technologies. The simultaneous connections are established by the user using multipath routing or data forwarding protocol included with several interfaces. The aim of the utilization of the multiple paths is not only considering single point of failure scenarios but also to focus on facilitating the whole network condition, where its performance is indeed essential for maximizing high quality network services which was discussed by Golubchik et al (2002) and Chen et al (2010). Bandwidth aggregation and load balancing capability of the network are two other issues, that have attracted large amount of research, and number of load distribution approaches had been proposed in literature.

The routing of sensed data is routed from the source to sink node in a resource constrained environment for the Wireless Sensor Network (WSN) which is still a challenge. Radi et al (2012) and Yick et al (2008) presented about the protocols which are available for routing the data in resource constrained scenarios. Different optimization techniques have been used for the routing protocols to find the optimal path between the source and destination. The selected optimal path is required to satisfy the resource constraints such as energy, bandwidth and computation power. The performance metrics of routing protocols are minimum hop distance, minimum transmission cost, high residual energy of the nodes etc. The minimum hop distance based protocol was discussed by Zheng et al (2009) and minimum transmission cost based routing protocol was proposed by Cheng et al (2010). The network life time may increase by selecting an optimal path between the source and destination and transmitting the sensed data through that specific path. Hou et al (2006) proposed the optimal single-session flow routing for enhancement of the network lifetime. The outcome of any designed routing protocol is required to fulfill the different performance demands such as delay, throughput, data reliability etc., for various applications.

The different types of routing protocols based on single path were discussed by Akkaya & Younis (2005) and Al-Karaki & Kamal (2004) and multipath routing was discussed by Radi et al (2012) in the network layer. Existing routing protocols in wireless sensor networks are designed based on the single-path routing algorithm in which the effect of various traffic load conditions is not addressed. Due to this reason, single-path routing approaches cannot be considered as an effective protocol to meet the deadline which is a performance limitation of WSN for certain critical applications. To overcome these limitations of single path routing protocol, another type of routing strategy, called multipath routing approach, has become a promising technique for network performance improvement. Multipath routing protocols construct several paths from every source node towards the destination node. The main advantage of multipath routing protocol is that, each source node uses only one path for data transmission and it switches on to another path if there is an occurrence of any node or link failure.

4.2. LITERATURE SURVEY

Zhang & Shen (2010) discussed an Energy-efficient Beaconless Geographic Routing in wireless sensor networks (EBGR). In EBGR, ideal next-hop relay position on the straight line toward the sink by each node was calculated based on the energy, optimal forwarding distance, and the neighbour closest to its ideal next-hop relay position was selected by each forwarder. The handshaking mechanism such as the Request-To-Send/Clear-To-Send (RTS/CTS) was used in EBGR for the calculation of relay position and selection of neighbourhood relay position. Request-To-Send/Clear-To-Send (RTS/CTS) handshaking mechanism creates processor overhead. Due to the handshaking mechanism there may be an increase in end-to-end delay also.

The proposed OMR-BLD is effectively designed for delay minimization. It is also an event-driven routing protocol and it transmits the data through the selected optimal path only when an event or any abnormality occurs.

A multipath routing protocol based on clustering with Ant Colony Optimization (ACO) for Wireless Sensor Network was proposed by Yang et al (2010). Cluster head selection in the event area was done based on the residual energy of the node. Next the multiple paths between cluster head and sink node were obtained by using Ant Colony Optimization and the route to transmit data was selected by CH dynamically. The ACO based algorithm concluded that the load balancing can be obtained by choosing the transmission path dynamically. This path selection was done by considering only one parameter such as energy. ACO is the most commonly used optimization algorithm which uses the amount of pheromone as the criteria for finding the optimal route.

In OMR-BLD protocol, MIWD algorithm is used to find the optimal path. It is a nature inspired optimization algorithm. In this Thesis the optimized load balancing multipath routing protocol being developed for maintaining equal load among the sensor nodes in the network to increase the network lifetime because of the improved load balancing strategy incorporated in the protocol.

Shivamurthy et al (2012) proposed a secure Energy Efficient Node Disjoint Multipath Routing Protocol (EENDMRP). It is a sink initiated proactive multipath protocol. Some of the security threats like spoofing, sinkhole attack, etc., were addressed. This protocol used the digital signature based cryptosystem for security aspects. Security was designed based on the MD5 hash function and RSA algorithm. This protocol considered two phases, route construction phase and data transmission phase. In Route construction phase, RCON packets were broadcasted by every node and routes were constructed based on the nodes' energy, number of hops, etc., but not on the network traffic. After completing the construction phase, each node had a routing table. In the next phase the data was transmitted to the sink node through primary path, which was chosen from the available multiple paths based on the threshold energy level and maximum path cost. The asymmetric (public) key crypto system was used for designing the security in EENDMRP.

The OMR-BLD protocol addresses the impact of network traffic on the performance characteristics. Through the performance analysis, the algorithm proves that the OMR-BLD has achieved the load balancing capability.

Some of the existing multipath protocols were discussed by Radi et al (2012). The main design issues such as reliability and fault-tolerance, load balancing and bandwidth aggregation in the development of the existing multipath routing protocols were discussed. In these multipath routing protocols, multiple paths were constructed by using number of components and the network traffic was distributed over the discovered paths. The main task of the path discovery process was to find a set of intermediate router nodes that should be selected to construct multiple paths from the source nodes towards the destination node. After the completion of path discovery, the adequate numbers of paths were selected for data transmission. The proposal of a perfect path selection mechanism is the most important part of designing multipath protocol but it is less addressed in the existing multipath protocol.

Hoang et al (2012) proposed an optimal data aggregation tree in wireless sensor networks based on intelligent water drops algorithm. The problem of constructing the optimal data aggregation tree of a densely deployed WSN was addressed. Optimized aggregation tree was obtained by finding the number of aggregation nodes and the connection between the two different nodes was obtained by minimizing the total number of edges. The optimal or near optimal tree was achieved by using Intelligent Water Drop (IWD) optimization algorithm that may provide a suitable solution for routing data. The author used the existing IWD algorithm for constructing the optimal tree. The tree was constructed based on the residual energy of the node.

The MIWD algorithm is proposed in the *Optimized Multipath Routing for Balanced Load Distribution (OMR-BLD) protocol* to find the optimal path for routing. The OMR-BLD uses the MIWD algorithm to find the optimal path for data transmission based on the residual energy of the node (R_E) and the number of packets in the queue (Q_L). These selection criteria improve the load balancing capability, thereby the lifetime of the network also increase.

In the present work discussed in this Chapter, the problem of obtaining the optimal route for routing the data from various sources to a destination/base station (BS) is addressed. Although the existing multipath algorithms presented above have some advantages, there still exists some shortcomings that prevent their applications in WSNs. The main short coming observed from the literature survey is that, the path selection algorithms are less addressed. To overcome the disadvantages of these algorithms and balancing the load among the nodes, this Thesis proposes an Optimized Multipath Routing for Balanced Load Distribution (OMR-BLD) protocol using improved Intelligent Water Drop (IWD) algorithm.

4.3. MULTIPATH ROUTING IN WIRELESS SENSOR NETWORKS

Single-path routing approach is not able to provide high data rate transmission efficiently in wireless sensor networks because of the limited capacity of multi-hop path. One of the solutions to handle this limitation is multipath routing protocol. The various types of existing multipath protocol and primary motivations behind using multipath routing approach were discussed by Radi et al (2012) which are presented in the following section.

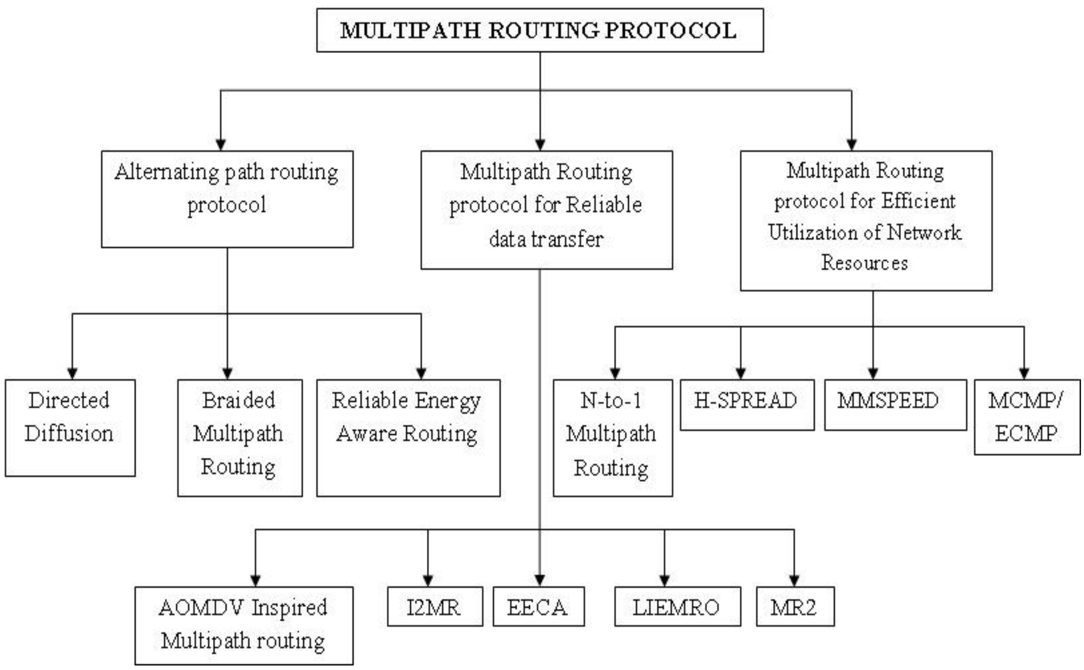

Figure 4.1 Types of Multipath Routing Protocols

Many types of multipath routing protocols are derived from the three main categories such as Alternating path routing, Multipath routing protocol for reliable data transmission and Multipath routing protocol for efficient utilization of network resources. There are a number of multipath routing protocols which have been designed based on these three basic types. The protocol designed based on these three categories are listed in the Figure 4.1 and is discussed in the following sub-section.

4.3.1. Directed Diffusion

Directed Diffusion was discussed by Intanagonwiwat et al (2000). It is a query-based alternate path routing protocol. The concept of multipath routing is used to provide the path failure protection. It is a sink initiated protocol which floods the interest message. After reception of an interest message, the receiver node creates a gradient towards the node from which the interest message has been received. In this way a number of paths can be discovered between source-sink nodes. After that, if any event occurred in source node, which matches with the information provided in the interest message, the source node transmits information to the sink node through several gradient paths. On reception of this information through several paths, the sink node selects the best path based on the minimum latency and transmits the reinforcement message. Then, the source node transmits the data through the selected path. This protocol does not provide an efficient route discovery mechanism because route discovery and path maintenance of this protocol is done by using low-rate flooding and it can be only used for query-driven applications.

4.3.2. Reliable and Energy-Aware Multipath Routing

Reliable and energy aware multipath routing protocol was proposed by Hassanein & Luo (2006). It is also a sink initiated routing protocol. If the sink receives the interest message but there is no active path towards the source node, it starts flooding the service-path-request message to discover the service-path. After receiving the service-path request message, the receiver node transmits a service-path reservation message to the sink node to authenticate the discovered path. The service-path reservation message moves from the source node towards the sink node. When an intermediate node receives this message, the part of the nodes' residual energy is reserved for data transmission over this path. The service-path construction process is completed only when the sink node receives the service-path reservation message. Then, data packets are transmitted towards sink node from source node through the constructed path. Another path discovery process is initiated by the sink to establish a backup path towards the same source node after constructing the service-path. This backup path is established by flooding a backup path discovery message. During this process, node disjoint path is created, eventhough this protocol provides energy-efficient and reliable data transmission, it has some drawbacks. The main draw backs are: it does not consider the effect of wireless interferences and reliability of the link.

4.3.3. N-to-1 Multipath Routing

N-to-1 Multipath Routing Protocol was discussed by Lou (2005). The main aim of this protocol is to discover the multiple node-disjoint paths for data transmission from all the source nodes towards the sink node. The multiple numbers of routing paths were constructed by flooding route update message and used the spanning tree algorithm. At the end of the path discovery process a complete routing tree was constructed. At last, the source nodes divided the traffic into a number of segments and these data segments were distributed over the discovered node disjoint paths. This protocol improves the reliability for packet delivery because of splitting the traffic among multiple paths. It uses simple flooding for constructing multiple paths. This may not construct minimum interference high-quality paths.

4.3.4. Ad Hoc On-Demand Multipath Distance Vector Routing (AOMDV)

AOMDV is a multipath routing protocol for efficient utilization of network resources. It extends the AODV protocol to discover multiple paths between source node and destination node or sink and was discussed by Marina & Das (2006). This protocol was proposed for the applications based on the ‘on demand’ basis. It found the route using route discovery phase. In each route discovery phase, multiple routes have been established between source and destination. Whenever a route was needed, the route discovery procedure was used in AOMDV to find multiple paths. These multiple paths were established by exchanging the Route Request (RREQ) and Route Reply (RREP) packets. This protocol used alternate route only when there was a route failure. In AOMDV, new route discovery was needed only when all the routes were failed.

In addition to the above multipath routing protocol, some other protocol such as Braided multipath routing, Reliable energy aware routing, Interference-Minimized Multipath Routing Protocol (I2MR), Energy-Efficient and Collision-Aware Multipath Routing Protocol (EECA), Low-Interference Energy-Efficient Multipath Routing Protocol (LIEMRO), Maximally Radio-Disjoint Multipath Routing (MR2), Hybrid Multipath Scheme for Secure and Reliable Data Collection (H-SPREAD), Multipath Multispeed Protocol (MMSPEED), Multi-Constrained QoS Multipath Routing(MCMP) / Energy Constrained Multipath Routing (ECMP) were also discussed in the various literature survey.

4.4. OPTIMIZATION TECHNIQUES FOR WSN

4.4.1. Ant Colony Optimization (ACO)

Yang et al (2010) proposed Ant Colony Optimization (ACO) for wireless sensor networks. The first ACO algorithm is Ant System, which was introduced by Dorigo & Gambardella (1997), for Travelling Salesman Problem. The main goal of ACO algorithm is to find the shortest distance to cover series of cities. It is a very simple algorithm and it works, based on the ant’s pheromone (Dorigo & Stutzle, 2004), each making one of the possible round trips along the cities. At each stage, the ant follows some rule to choose a path between two points. Some of the rules are:

- It must visit each city exactly once.
- There is less chance for a distant city being chosen.
- The edge between two cities has more intense of the pheromone which will be chosen with greater probability.
- If the journey is short, the ant deposits more pheromones on all edges it traversed.
- After completion of each iteration, trails of pheromones evaporate.

The same algorithm was used by Yang et al (2010) for finding the shortest distance for network routing.

4.4.2. Intelligent Water Drop (IWD) Optimization

Intelligent Water Drop algorithm was developed by Shah-Hosseini (2002). It is an optimization algorithm having a step in a way to model a few actions that occur in natural rivers and then to implement in the form of an algorithm. In IWD algorithm, velocity and the amount of soil carried are the two main properties, which are used to create IWDs. These two properties may vary during the lifespan of IWD. The IWD starts its journey from source to destination with an initial velocity and zero soil carried. During its journey, it travels in different environment and flows in discrete steps. In this algorithm the velocity of IWD is changed according to the amount of soil that the IWD carried between two locations. This means that the velocity of IWD is inversely proportional to the amount of soil carried. Thus, the IWD flows with high velocity when there is a path with less amount of soil carried, than a path with more amount of soil carried.

During the travel, IWD needs a method for selection of path for its next location or step. For this, it gives more preference to the paths having low amount of soil carried than the paths having high amount of soil carried. This path selection algorithm uses the uniform random distribution. The probability obtained from this uniform random distribution is inversely proportional to the amount of soil carried on the available paths. Therefore, the path with lower amount of soil carried is getting more chance to be selected by the IWD.

In this Chapter, the same concept with Modified IWD (MIWD) optimization is proposed here as OMR-BLD. In OMR-BLD the MIWD is used to find the optimal path for routing packets. The proposed algorithm uses the *queue length* (Q_L) which is defined as the number of packets on the queue and the *residual energy (RE)* of the node are the two important parameters for finding optimal path. In OMR-BLD, the path with less Q_L and high R_E has higher chance to be selected as an optimal path for routing data.

4.5. NETWORK SYSTEM MODEL FOR OMR-BLD

The following assumptions are made for the network system model for OMR-BLD

- This model is the homogeneous system model which means all nodes have the same initial energy and communication range.
- When an event occurs, source node needs to transmit data to BS through the routers.
- The nodes are battery powered and are comprised of sufficient memory capacity to execute communication and computation capabilities.

- The sensor nodes are randomly deployed in the network area. They are static in nature and every node has a unique node-ID.
- For the proposed protocol, the nodes in the network are configured to perform like source node, router, destination node or Coordinator or Base Station. Each source node can communicate with destination by first forming the primary path through route nodes.

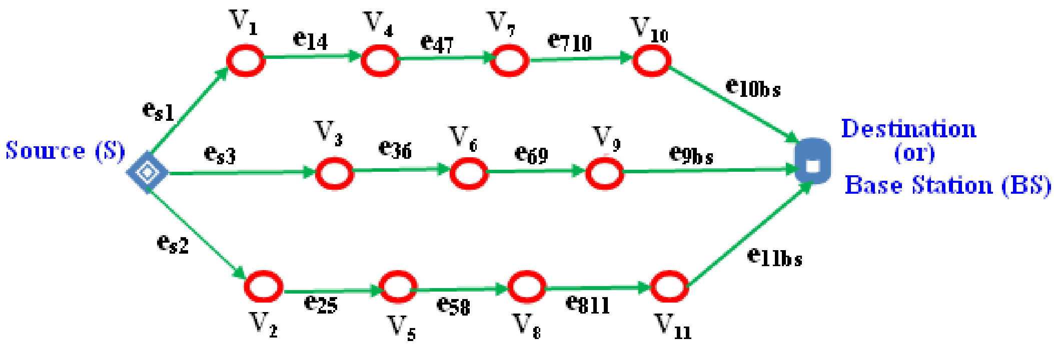

Figure 4.2 Network Model for Multipath Routing

In order to obtain the load balancing in WSN, the route nodes in the network need to forward equal number of packets. This means that the number of paths/routes should be multiple. A wireless sensor network comprises of a base station communicating like a receiver to large number of sensor nodes. The network can be represented as a directed graph G. The graph G is defined as follows: G = (V, E), where V= $\{v_1,v_2,v_3,.., v_n\}$, V is a set of vertices and each vertex denotes a sensor node and E=$\{e_1,e_2,e_3,\ldots,e_m\}$, E is a set of edges and each edge denotes a link between vertices (i.e., sensor nodes). For two arbitrary integers i and j, where i and j are less than n which is number of nodes in the network, e_{ij} indicates a communication link between vertex v_i and v_j. An in-degree (and out-degree) is the number of inward (and outward) graph edges from a given graph vertex in the directed graph. The Figure 4.2 shows network model for multipath routing which is developed from the model using graph theory concept discussed by Vasudev (2006).

4.6. MODIFIED IWD (MIWD) OPTIMIZATION FOR OMR-BLD

Intelligent Water Drop (IWD) discussed by Shah-Hosseini (2002) is a swarm-based nature-inspired optimization algorithm which is based on the flow of natural water drop and has similar properties to find the optimal paths to their destination. The water drops follow these near optimal or optimal paths for actions and reactions occurring within their riverbeds. In the IWD algorithm, IWDs are created with two main properties: the soil it carries denoted by soil(IWD) and the velocity that it possesses, denoted by velocity(IWD). For each IWD, the values of both properties, soil(IWD) and velocity(IWD) may change as the IWD flows in its environment. In an environment there is more than one path available from source to destination and the position of the destination may be known or unknown. The goal is to find the optimum solution or path from the source to the destination.

Based on the Hoang et al (2012) and Intanagonwiwat et al (2000) the Modified IWD optimization algorithm (MIWD) is derived as follows, by replacing the parameters appropriately. In the MIWD algorithm, paths are found based on two main parameters: the number of packets in the queue denoted by Q_L and the residual energy that the node possesses denoted by R_E. The modified IWD algorithm has two kinds of parameters. Those that remain constant are called ‘static parameters’ and the other kind are those parameters of the algorithm which are dynamic that need to be reinitialized after completion of each iteration of the algorithm.

The modified IWD algorithm is specified as follows,

Step 1: Static parameters Initialization: The graph (V, E) of the problem is given to the algorithm. The quality of the best solution T^B is initially set to the worst value: $q(T^B)=\infty$. The number of nodes in the network N_{IWD} is set to a positive integer value.

Moreover, the initial Queue Length (Q_L) on each path (edge) is denoted by the $InitQ_L$ such that the number of packets in the queue of the path between every two nodes i and j is set by $Q_L(i\ j)=InitQ_L$ and the Residual energy R_E of the node is $InitR_E$. Both parameters $InitQ_L$ and $InitR_E$ are defined by the user and they should be tuned experimentally for the application.

Step 2: Dynamic parameters initialization: Every packet has a visited node list $V_C(MIWD)$, which is initially empty, that is, $V_C(MIWD)=\{\}$. Each node's residual energy is set to $InitR_E$.

Step 3: Randomly spread packets on the nodes of the graph as their first visited nodes and Update the visited node list of each packet to include the nodes just visited.

Step 4: Repeat Steps 4.1 to 4.4 for those packets with partial solutions.

4.1 For the packets residing in node i, choose the next node j, which does not violate any constraints of the problem and is not in the visited node list $V_C(MIWD)$ of the Modified intelligent Water Drop (MIWD), using the following probability $P_i^{MIWD}(j)$:

$$P_i^{MIWD}(j) = \frac{f(Q_L(i,j))}{\sum_{m \notin V_c(MIWD)} f(Q_L(i,m))} \tag{4.1}$$

Such that,

$$f(Q_L(i,j)) = \frac{1}{\varepsilon_s + g(Q_L(i,j))} \tag{4.2}$$

$$g(Q_L(i,j)) = \begin{cases} Q_L(i,j) & \text{if } \min(Q_L(i,l)) \geq 0 \\ Q_L(i,j) - \min(Q_L(i,l)) & \text{else} \end{cases} \tag{4.3}$$

where $l \notin V_C(MIWD)$. Then, newly visited node 'j' is added to the list $V_C(\ MIWD)$ and i, j, m are nodes in the network.

4.2 For each packet moving from node *'i'* to node *'j'*, update its residual energy by,

$$R_E^{MIWD}(t+1) = R_E^{MIWD}(t) + \frac{a_v}{b_v + c_v \cdot Q_L^2(i,j)} \tag{4.4}$$

where $R_E^{MIWD}(t+1)$ is the updated Residual energy of the node and a_v, b_v and c_v are pre-defined positive parameters used for update of residual energy in the node for the MIWD algorithm.

Table 4.1 Parameters used for MIWD Algorithm

Notation	Description	Values
$InitR_E$	Initial Residual Energy	1J
$InitQ_L$	Initial Queue Length	50 Packets
a_v,b_v,c_v	Residual energy updating parameters	1,0.01,1
a_s,b_s,c_s	Queue Length updating parameters	1,0.01,1
ε_s	Constant	0.01
$\rho_n/\ \rho_{MIWD}$	Local RE updating parameter/ Global RE updating parameter	0.9(<1)

4.3 For the packet moving on the path from node *‘i’* to *‘j’*, compute the queue length $\Delta Q_L(i, j)$ that the packet loads from the path by,

$$\Delta Q_L(i,j) = \frac{a_s}{b_s + c_s \cdot time^2(i,j;R_E{}^{IWD}(t+1))} \tag{4.5}$$

a_s and c_s define the relationship between the number of packets and the period of time the packet takes to move through the *edge or node (i, j),* and b_s is a small number used to avoid the singularity problem. The values used for the evaluation of the algorithm (Shah-Hosseini 2002) are listed in Table 4.1.

Such that,

$$time(i,j;Q_L(t+1)) = \frac{HUD(j)}{R_E{}^{MIWD}(t+1)} \tag{4.6}$$

where the heuristic undesirability $HUD(j)$ is defined appropriately for the given problem.

4.4 Update the $Q_L(i,j)$ of the path from node *‘i’* to node *‘j’* traversed by that packet and also update the packet by,

$$Q_L(i,j) = (1-\rho_n)\cdot Q_L(i,j) - \rho_n \cdot \Delta Q_L(i,j) \tag{4.7}$$

$$Q_L^{MIWD} = Q_L(i,j) + \Delta Q_L(i,j) \tag{4.8}$$

5. The Iteration best solution T^{IB} is obtained by using all the solution found for each iteration by packets T^{MIWD} and is given by,

$$T^{IB} = \arg \max q(T^{MIWD}) \tag{4.9}$$

6. Update the packets on the queue that form the current iteration-best solution T^{IB} by,

$$Q_L(i,j) = (1+\rho_{MIWD}) \cdot Q_L(i,j) - \rho_{MIWD} \cdot \frac{1}{(N_{IB}-1)} \cdot Q_{L\,IB}^{MIWD} \forall (i,j) \in T^{IB} \quad (4.10)$$

where N_{IB} is the number of nodes in the solution T^{IB}.

7. Update the best solution T^B by the current iteration-best solution T^{IB} using

$$T^B = \begin{cases} T^B & if \quad q(T^B) \geq q(T^{IB}) \\ T^{IB} & otherwise \end{cases} \quad (4.11)$$

The Modified IWD algorithm stops with best solution T^B.

In the proposed multipath network system model, the network is simulated with three node-disjoint paths. These three paths are having average R_E = 0.8J, 0.5J, 0.9J; Q_L = 35, 15, 49. The optimization parameters listed in Table 4.1 are used for iteration evaluation. The evaluation of the proposed algorithm for OMR-BLD protocol is given in Appendix 1. After completion of all the iteration, the optimal solution is obtained based on the updated residual energy and queue length. In the above evaluation process, optimal solution is obtained in the second iteration. The optimal solution obtained from the iteration is taken as primary path for routing data.

4.7 OMR-BLD PROTOCOL

4.7.1 Path Discovery Phase

The process of data transmission in wireless sensor networks is commonly performed through multi-hop data forwarding techniques. Therefore, the main task of the path discovery process is to determine a set of intermediate router nodes that should be selected to construct several routes between the source node and the destination node. OMR-BLD is a node disjoint multipath routing protocol. In this process, multiple paths are found by exchanging *Path DIScovery (PDIS) packets* between nodes. The process of path discovery is shown in Figure 4.3. Each sensor node broadcasts *PDIS* (Path DIScovery) packet and discovers multiple paths. The format of the *PDIS* packet is as shown in the Table 4.2. It includes forward node-id which indicates the next hop node-id; the backward-id to indicate the previous hop node-id and node's residual energy. The packet type indicates whether the packet is a control packet or a data packet. The queue length represents the number of packets in the queue and hop count about the number of hops that the packet has traversed from source node.

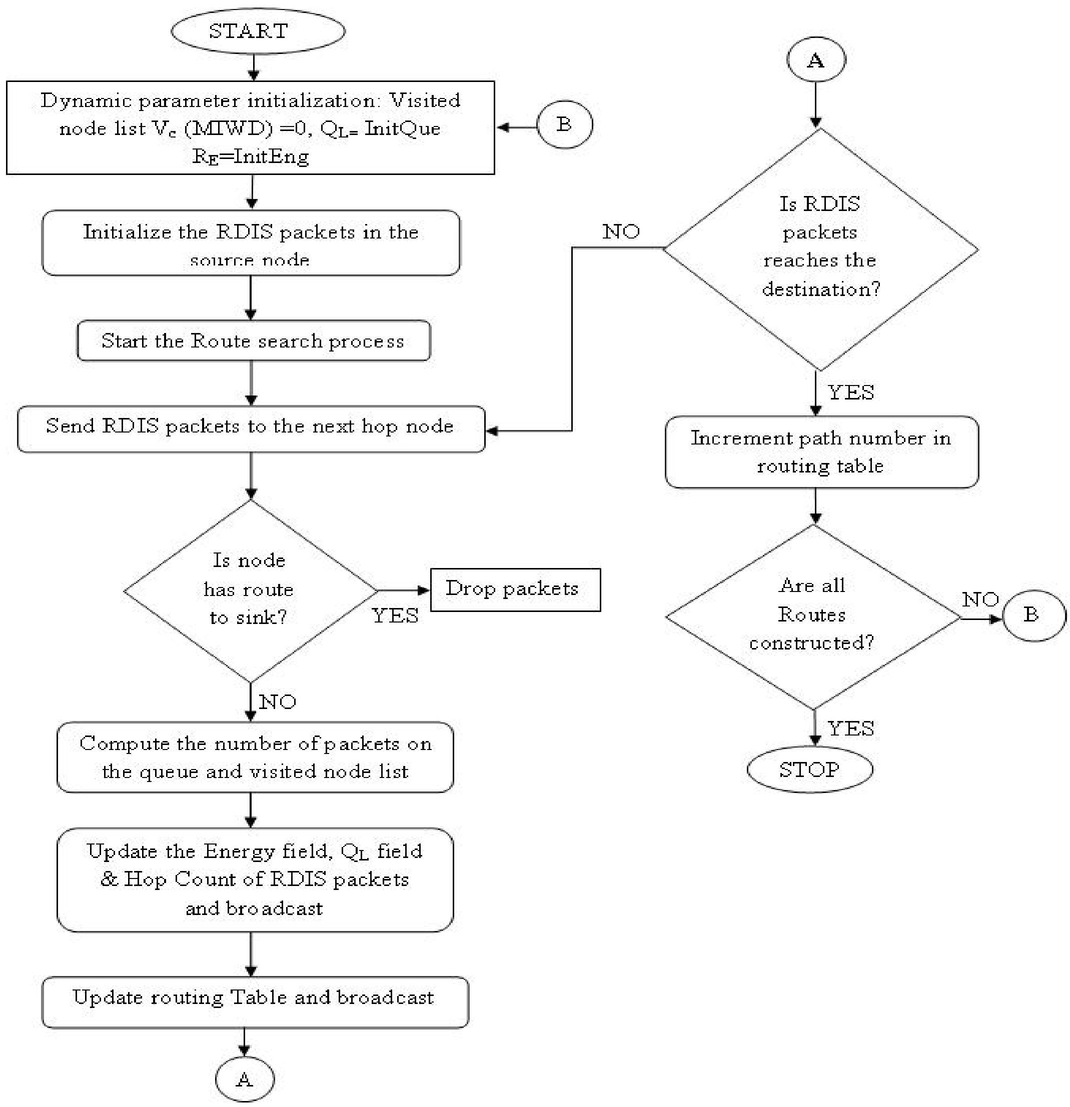

Figure 4.3 OMR-BLD: Path Discovery Phase

In path discovery process, dynamic parameters are initialized first. The dynamic parameters queue length (Q_L) and residual energy (R_E) are initialized as InitQ_L and InitR_E respectively and the visited node list V_C(MIWD) is initially empty that is, V_C(MIWD)={}. The source node in the network which is connected to the electrical system initializes the PDIS packet for path finding purpose. If the node that received *PDIS* packet has no path to the sink, then that node processes the PDIS packet. If the path to sink is already available in the node's routing table, then it checks the residual energy of the node and the number of packets on the queue. If the residual energy of the node is above threshold value and its queue length is smaller, then PIDS is processed; otherwise the packet is dropped.

The node that receives the *PDIS* packet, updates the *PDIS* packet. The updated *PDIS* with hop count gets incremented by updates of the forward node id and adds its node-id to the path. After receiving the path discovery packet, the node updates its routing table information. Similarly, all the nodes in the network update their routing table after receiving the path discovery packet. This process is repeated until all the nodes in the network generate their routing table. The routing table contains node-id, queue length, hop count, residual energy, path number and all the available node disjoint paths. The node disjoint path indicates the number of node disjoint paths between source node and sink node. The routing table format is shown in Table 4.3.

Table 4.2 Path DIScovery Packet Format

Packet Type (1 byte)	Queue length (2 bytes)	Hop count (2 bytes)	Residual Energy (4 bytes)	Next hop node-id (2 bytes)	Previous hop node-id (2 bytes)

Table 4.3 Routing Table Format

Node-id (1 byte)	Queue length (2 bytes)	Hop count (2 bytes)	Residual Energy (4 bytes)	Path number (2 bytes)	Node-disjoint paths (2bytes)

4.7.2 Path Selection and Load Distribution Phase

After construction of multiple node disjoint paths, selection of sufficient number of paths for data transmission purpose is the next issue. According to the main purpose of designing each multipath routing protocol, a certain number of paths should be selected to meet the performance demands of the intended application which was discussed by Hassanein & Luo (2006), Marina & Das (2006) and Tarique et al (2009). Therefore, proposing a perfect path selection mechanism to select adequate number of paths is the most significant part of designing a high performance multipath routing protocol.

OMR-BLD protocol proposed in this Chapter may decide to use the best path as the optimal and primary path for data transmission and keep two additional paths as the secondary paths for reliable data transmission. The primary path is obtained by using the Intelligent Water Drop optimization algorithm. This algorithm gives the satisfactory near optimal solution. In OMR-BLD protocol, IWD algorithm determines a set of paths selected among the discovered node disjoint paths. OMR-BLD distributes the network traffic over the specific primary path and the secondary path is selected whenever the primary path fails to meet the criteria.

The key idea of the proposed protocol is to distribute the traffic evenly among the selected paths thereby improving the reliability of the data and minimizing the end-end delay. This optimized protocol reduces the duplication of the data received by the destination. The proposed OMR-BLD protocol with MIWD optimization algorithm is explained in the Figure 4.4.

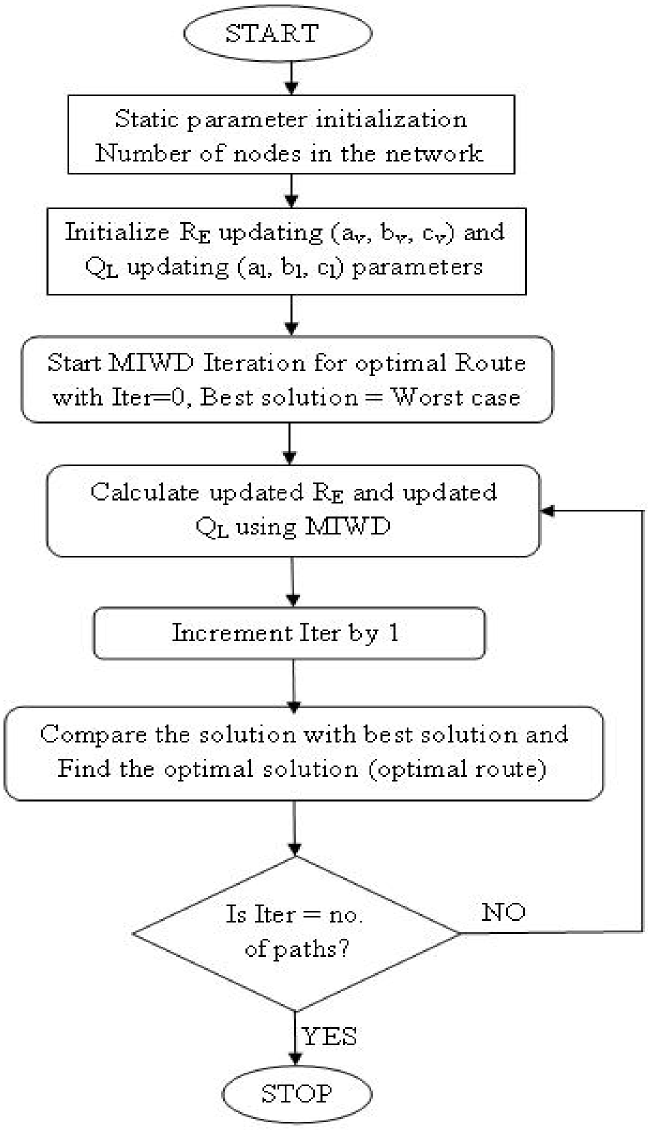

Figure 4.4 OMR-BLD: Path Selection Phase

4.7.3 MIWD for OMR-BLD

The dynamic parameters of the proposed OMR-BLD are first initialized. The dynamic parameter such as residual energy updating parameters a_v, b_v, c_v are initialized with the values of 1, 0.01, 1 respectively and queue length updating parameters a_l, b_l, c_l are initialized with the values of 1, 0,01, 1 respectively.

The source node starts the path search process by initiating the MIWD packet and sends MIWD packets to the next hop node. Table 4.4 shows the format of MIWD packet. In this format the field P_type indicates the type of packet whether the packet is 'control packet' or 'data packet'. S_Node-id indicates the identity of the source node who initiated the MIWD packet. P_Node-id and N_Node-id represent the previous hop node-id and next hop node-id respectively. Hop-count indicates the number of hops from the current node to the source node. $MIWD\_R_E$ and $MIWD\_Q_L$ are the MIWD updating parameters and the initial value set $MIWD\_R_E$ and $MIWD\_Q_L$ is set by $InitR_E$ and $InitQ_L$=0.

The last field is the payload field. After receiving MIWD packets the next hop nodes update the energy field and the queue length field of MIWD packet. The queue length field of MIWD packet is updated after calculating the number of packets on the queue. The updated packet is transmitted to next hop neighbourhood nodes until it reaches the destination node or BS which is the substation. If the destination is reached, it checks whether all the routes are constructed. Otherwise it again repeats the same steps from sending MIWD packets. Once all the routes are constructed, the optimal path is found by using MIWD algorithm. If not, it reinitializes the parameters and repeats the steps. Finally, optimal path is selected as primary path for data transmission after completion of maximum iteration.

Table 4.4 MIWD Packet Format

P_Type	S_Node-id	P_Node-id	N_Node-id	Hop count	$MIWD\_R_E$	$MIWD\_Q_L$	Payload

4.8. PERFORMANCE ANALYSIS

The OMR-BLD is simulated using NS2 network simulator (Network Simulator NS2). Simulation of wired as well as wireless network functions and protocols (e.g., routing algorithms, TCP, UDP) can be done using NS2. Table 4.5 shows the parameters used for simulation of the proposed protocol. The proposed protocol is simulated with 100 nodes having equal initial energy of 1J and transmission coverage range of 40m. The MAC protocol used in this simulation is IEEE 802.15.4, which is a standard for WPAN and it is operated on the frequency of 2.4 GHz.

Table 4.5 Simulation Parameters

Parameters	Settings
Number of Nodes	10-100
Radio Transmission range	40 m
Number of Sources	2-10
Node Mobility	None
Initial Energy Of Sensor Nodes	1 J
Transmission Energy	0.3 µJ
Reception Energy	0.3 µJ
MAC Protocol	IEEE 802.15.4
Routing protocol	OMR-BLD
Propagation Model	Two ray Ground Model
Queue Type	Drop Tail
Queue Size	50
Data Transfer Model	Direct Data Transmission

4.8.1 Load Balancing Capability

The OMR-BLD protocol has the metric reflecting longer life-term energy efficiency for the network due to load balancing capability of the proposed routing protocol as observed in Figure 4.5.

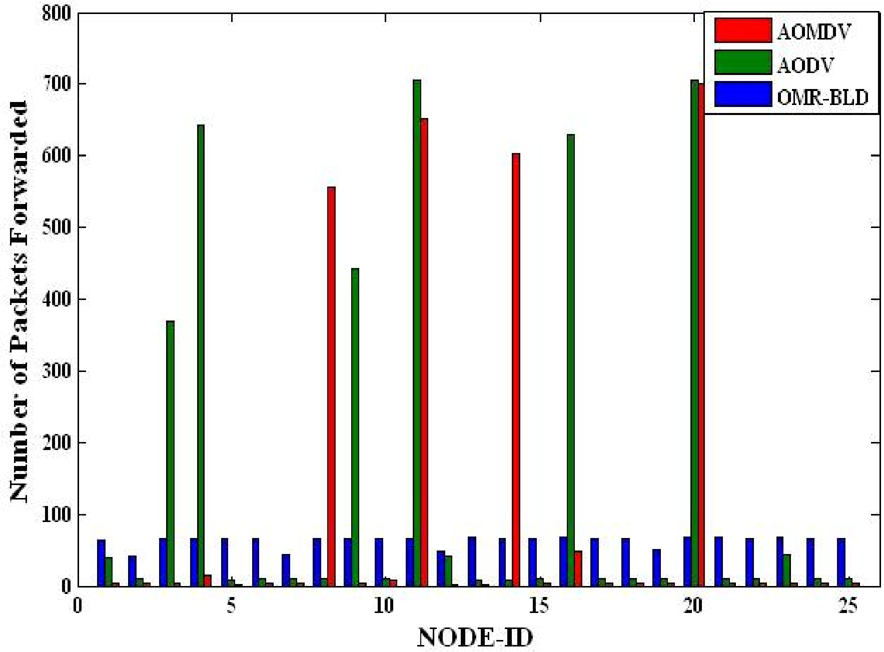

Figure 4.5 Load Balancing Capability of OMR-BLD

From the result, it is observed that the average number of packets forwarded by Node-ID 4 is 643 in AODV, 14 in AOMDV and 66 in OMR-BLD routing protocol. Similarly, the average number of packets forwarded by the Node-ID 8 is 9 in AODV, 556 in AOMDV but it is the same 66 in the proposed OMR-BLD protocol. It shows that the OMR-BLD protocol evenly maintains the number of packets forwarded by each router node in the network thereby enhancing the network life time compared to other standard protocols such as AODV, AOMDV wherein the average packets forwarded by each node varies abruptly.

4.8.2. Packet Delivery Ratio

Figure 4.6 shows the Packet Delivery Ratio (PDR) of the network when density of the network increases and Figure 4.7 shows PDR of the network when the number of sources increases. The performance of PDR decreases with the increase in the density of the network in all the three routing protocols though the proposed OMR-BLD has achieved 96.5% as PDF when the network density is 100. This increased packet delivery ratio is achieved because of the use of optimized multipath selection for routing. When the network is configured with 100 nodes, the OMR-BLD protocol has achieved PDR of 96.5% which is 14% higher than the AODV protocol and 7% higher than the AOMDV protocol.

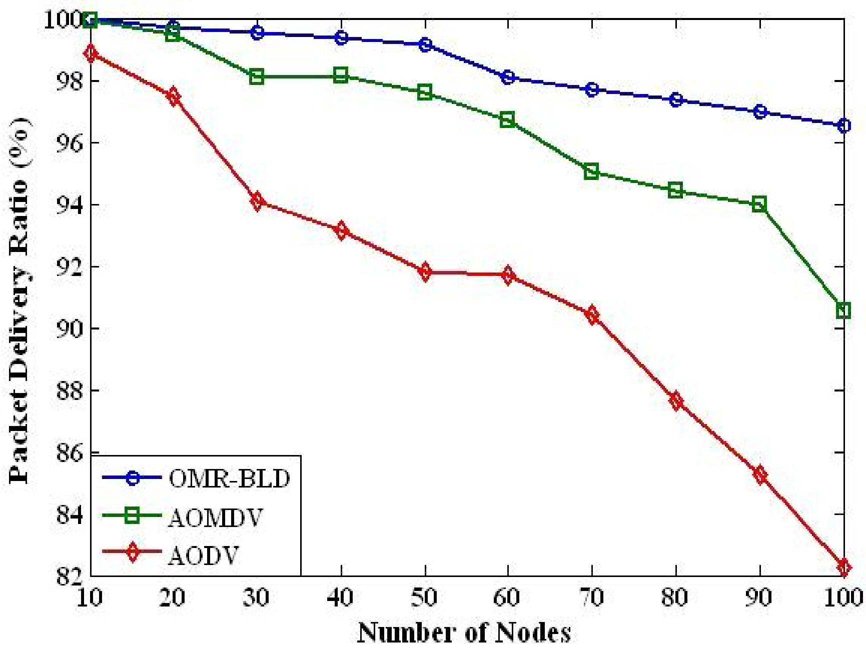

Figure 4.6 Increased Packet Delivery Ratio with Increase in Network Density

Similarly, the PDR performance of the OMR-BLD with various numbers of sources is shown in the Figure 4.7. From the result, it is observed that, when the number of sources in the network is 2, the PDR of the AODV and AOMDV routing protocol is nearly 40% and 52% respectively, but the OMR-BLD has achieved nearly 90%. When the number of sources increase, it maintains PDR between 90% and 95% which is higher as compared to AODV and AOMDV since it enters into communication through optimal path selection based on the Modified IWD algorithm whenever an event occurs in the network.

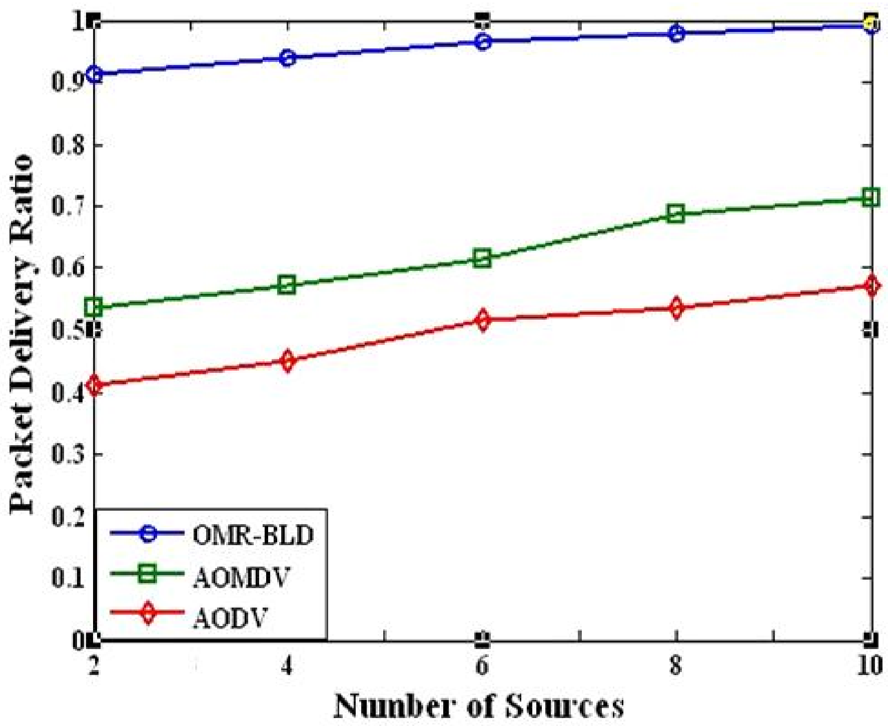

Figure 4.7 Packet Delivery Ratio vs. Number of Sources

4.8.3 End-to- End Delay

Table 4.6 shows the end-to-end delay incurred in sending the data from the source node to destination node in the AODV, AOMDV and OMR-BLD protocols. The end-to-end delay is reduced in the OMR-BLD Protocol as compared to the AODV and AOMDV standard routing protocols since the number of packets in the queue is one of the criteria to find routing paths. OMR-BLD has lesser end-to-end delay otherwise seen in AODV, AOMDV because of its reactive nature. Also, the modified MIWD algorithm for OMR-BLD protocol estimates the number of packets in the queue and the path discovery prior to the transmission with the end-to-end delay in OMR-BLD protocol maintained constant.

Table 4.6 End-To-End Delay

No.of Sources	AODV (msec)	AOMDV (msec)	OMR-BLD (msec)
2	1.9231	45.9087	2.125
4	2.6573	37.0688	2.349
6	3.1252	40.9345	2.416
8	8.9012	33.4703	2.482
10	13.062	29.6182	2.578

4.8.4 Energy Consumption

Linear increase of energy consumption occurs as the network becomes denser, since more sensor nodes become involved. It is obvious that OMR-BLD consumes less energy approximately 3.5 times lesser energy than the AOMDV and 8 times lesser than AODV as observed in Figure 4.8, since packet delivery is rescheduled to an alternate path whenever the queue length of a node exceeds, the optimized threshold as conceived in the OMR-BLD protocol. From the results, it can be observed, that the proposed protocol consumes less energy than AOMDV. The OMR-BLD protocol has each node in the route forwarding equal number of packets with balanced energy consumption by all nodes thereby obtaining load balance and energy efficient.

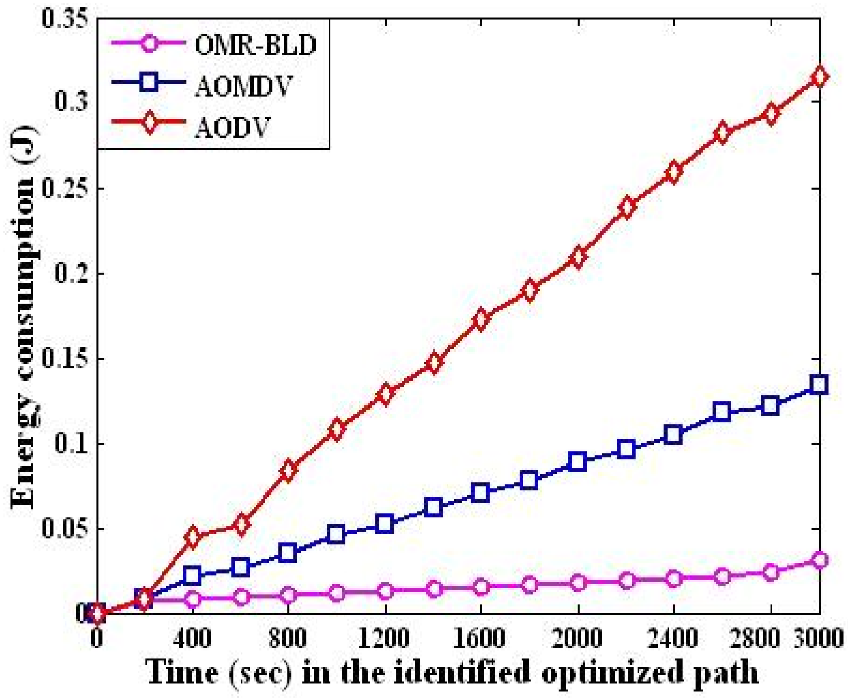

Figure 4.8 Energy Consumption Decreases due to Load Balancing Protocol

4.8.5 Network Lifetime

Figure 4.9 shows the network lifetime for the three protocols. It is evident that, when the density of the network is 100 and the initial energy of a node is 1J, the network lifetime achieved by OMR-BLD is almost 2.5 times improved over that obtained by AOMDV and 3.8 times over AODV which requires more time to establish a route for initial communication. The network size influences OMR-BLD the least. The reason is that the optimization algorithm involved for selection of the primary path to transmit data can greatly contribute to reduce energy consumption and to achieve load balancing among all nodes. When a path fails in the AODV protocol, it again repeats the process to find alternate route, and AOMDV protocol finds multiple routes during the route discovery phase and the route selection is random in nature. These protocols consume more energy during the establishment of the route or for finding alternate path with a higher probability for a node in the path to die earlier. However, in the OMR-BLD protocol whenever the route fails, it uses the alternate route using MIWD algorithm for finding the route with threshold limits thereby the network has longer lifetime.

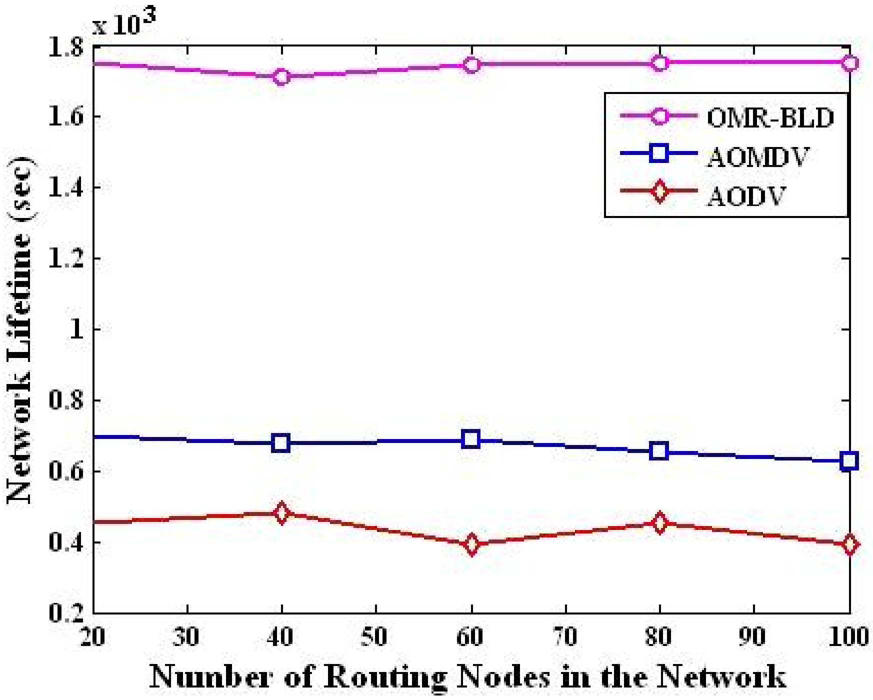

Figure 4.9 Lifetime of the Network due to MIWD Algorithm

4.9 CONCLUSION

This Chapter proposes the OMR-BLD protocol to increase the network lifetime by evenly distributing the load among the nodes. This can be achieved by using Modified IWD optimization algorithm (MIWD). Using the analytical model of MIWD, optimal path selection and uniform traffic distribution protocol are proposed which achieve better performance such as minimum delay, load balancing, increased PDR, minimum energy consumption and enhanced network lifetime. The optimal path vectored route based on OMR-BLD protocol uses the two criteria such as minimum number of packets forwarded by the node with requiring residual energy of the node to be greater than the optimal threshold energy estimated while finding the primary path. From the simulated results, the proposed protocol prove that there is an improvement of 14% in packet delivery fraction when traffic density increases, 40% in PDR when the number of sources increase and reduction of 71% in end-to-end delay when number of sources increases with also achieving load balancing as compared to single path routing protocol.

This Chapter proposed the optimized, efficient and load balanced routing protocol, but it does not discuss about the processing and security of the data packets, which means that the payload field of the packets. Each protocol requires the secured and reliable data transmission. It can be obtained by using crypt analysis for encrypting data before transmission. The next Chapter proposes the encryption technique for secured data transmission with reliability.