Cellular Automata Construction for Novel Routing over Hexagonal Grid for Mobile Ad-hoc Networks

A. Kumaravel*

Department of Computer Science, Bharath University, Chennai - 600073, Tamil Nadu, India; kumaravel.cse@bharathuniv.ac.in

Abstract

We address the problem of constructing an efficient route algorithm for Mobile Ad-hoc Network setting up QoS routes based on route discovery mechanism of AODV protocol and cellular automata. A Mobile Ad-hoc Network (MANET) consists of mobile nodes which are free to move arbitrarily due to its dynamic nature, adaptive and infrastructure less in nature. It is very tough task to have a snap of a network topology in this dynamic nature. Many research works have done to find a shortest path in MANET, it may give a better solution for finding an optimal path but difficult to augment with QoS constraints and its energy utilization. Here we have proposed an algorithm based on hexagonal cellular automata model for giving an efficient algorithm. This algorithm applies ADOV protocol and Lee's algorithm for constructing a shortest route and it considers energy and delay/bandwidth constraints as its basic metrics. These two metrics give a basic criterion for selecting a path between source and destination nodes through hexagonal cellular automata. Finally it is modeled with a matrix to implement it.

Keywords: ADOV, Cellular Automata, Hexagonal Grids, Lee Algorithm, Mobile Ad-hoc Networks, Quality of Service

1. Introduction

A mobile ad-hoc network (MANET) (Rappaport T. S., 2002) is a self forming dynamic network system comprising of mobile nodes, where each and every active node can communicate through wireless (radio signal) transmission. This kind of unplanned network system doesn't have any centralized controller or server, generally these dynamic topologies are called infrastructure less network systems. Each participating node in a MANET can move arbitrarily with different relative speeds. This ensures that there is no guaranteed path from any one node to other node. MANET is categorized into different application scenarios as it gives instance network where we need of urgent communication network. These kinds of network are used to form a communication platform for military operations and disaster relief operation to serve instantly without any complex infrastructure with low cost. MANETs are better solution to create a network where sparsely populated areas to give an effective and

traffic free communication. It is used in the organization to implement a temporary network for conducting seminars, presentations and other needs in campus activities. One of the main challenging aspects of an ad-hoc network is finding a shortest path (Abbas, A. M., Kure O., 2009) between two nodes for routing data packets with minimum delay and loss (Snthi, Nachiappan, 2010). So it should be the primary consideration for designing topology aware routing algorithm with minimum delay. The algorithm should ensure the effective utilization of battery resources to run the protocols specially designed for it.

There have been many protocols exist for MANETs, such as Adhoc On Demand Vector (AODV), Associatively-Based Routing (ABR) (C. K. Toh, 1996) Dynamic Source Routing (DSR) (Johnson, D.A. Maltz, 1996). Temporally Ordered Routing Algorithm (TORA) (V. Park et al., 2009) and etc. They are mostly designed for best effort transmission without any guarantee of quality of Service, adaptability and better energy saving, here the term QoS (Perkins and E. Royer, 2003) defines a network's ability to give a better service using presently available resource. It is used to prioritize the network performance by analyzing its level of guaranty in giving services to the operations. In general QoS parameters such as service response time, throughput packet delay, bandwidth and noise level will be used to analysis the guaranteed service of a network. For an ad-hoc network QoS is an important criteria to give reliable transmission of data with minimum usage of resources in a highly dynamic nature.

Many researchers are attracted by the cellular automata concept, as it is easily dealing with highly nonlinear and dynamic nature. Cellular automata are used to analysis very complicated phenomena like physical system with its simple mathematical definitions. CA (Azadesh Ghalavand et al., 2011) is applied in many areas like computer technology, biological simulations, chemical industries, cryptography systems, parallel computing and so on. CA consists of array of n-dimensional grids called cells with a finite number of predefined states. Transition rules will make changes a state of a cell based its neighborhood state.

2. Cellular Automata

A cellular automaton (CA) (S. Wolfram, 2002), (V. Park et al., 1997), (Hochberger et al., 1996) can be realized as partition over rectangular grids. Grids are defined by a finite set of states, for each state of a cell depends on that of the finite number of neighborhood grid cells. The state configurations are extracted with respect to the time stamps progressing sequentially. We knew that CA is a discrete event model, at time t=0 the initial state configuration of a cell is defined ant it will be chanced at t=1 increasingly. The new state of a cell is configured based on its neighborhood state and its own state by applying some fixed rules. Typically rules for configuring the state of a grid is common and it is applied simultaneously to all cell in a plane.

A Cellular Automaton can be formally defined as a 4-tuple (G, P, *N*, *h*) Where:

- G is a regular grid. The elements that compose this grid are called cells.
- *P* is a finite set of states, $P = \{0, 1, ..., p-1\}$.
- *N* is a finite set (of size | *N* | = n) of neighborhood index, such that ∀*c*∈ *N* and ∀*k* ∈ *G*: *k* + *c* ∈ *G*
- *h* : *P*ⁿ → *P* is a transition function *where n* is the size of the neighborhood.

A grid can be in any finite number of dimensions (e.g. a line or a cube of cells) and the time basis of the system is synchronous (t = 0, 1, 2...). A configuration $f_t: G \rightarrow p$ is a function that associates one state with one cell of the grid. The task of this function is to change the configuration f_t to a new configuration f_{t+1} (see equation1).

$$f_{t+1}(k) = f(f_t(i) \mid i \in N(k))$$
(1)

Where N(k) is the set of all neighbors of a cell k.

$$N(k) = \{i \in G \mid k - i \in N\}$$

$$\tag{2}$$

The two fundamental types of neighborhood in CA systems are von Neumann neighborhood and Moor neighborhood, these two standard radius-1 neighborhoods in a two-dimensional cellular grid are depicted in Figure1. The Moore neighborhood consists of eight surrounding cells of the center cell depending on whether or not the central cell is counted. And the von Neumann neighborhood consisting of four cell array - defined as north, south, east and west; that are strictly adjacent to the center cell.

3. Basic Algorithm Descriptions

In this section we are going to discuss the underlying algorithm for routing with minimum number of hops, delay and energy requirements over Cellular Automata. The basis algorithm considered for implementing hexagonal cellular automata is called Lee algorithm in (Azadesh Ghalavand et al., 2011). The path discovery algorithm will use AODV (Ad-hoc On-Demand Distance Vector) protocol to find shortest path between two nodes in an ad-hoc network (Azadesh Ghalavand et al., 2011). It is an on demand version protocol and it finds the shortest between any two nodes, when a source has data to transfer.

NW	N	NE			N	
w		Е		W		Е
sw	S	SE			S	

Figure 1. Moor neighborhood (right) & von Neumann neighborhood (left) in Two- Dimensional CA.

3.1 Lee algorithm

Let us see brief introduction about Lee algorithm (Azadesh Ghalavand et al., 2011; Hochberger et al., 1966) well known approach to routing problems. Its purpose is to find an optimal path between two points on a regular grid. At each node this algorithm considers only the least cost for moving to the next node. By adjusting the weights of the grid points the user has some control over what is supposed to be an optimal path. This algorithm works in two phases, the first phase is called wave mark assignment and the second phase is called routing based on wave path. For assigning wave marks of each node it uses different types of states. Initially it would be two start states like Init_S (Source node) and Init_D (Destination node).

3.2 AODV Protocol

Whenever a node needs to communicate with another one, it broadcasts a Route Request message (RREQ) to its neighbors. As stated in (Azadesh Ghalavand et al., 2011) they re- broadcast the message and set up a reverse path pointing towards the source. When the intended destination receives a RREQ message, it replies by sending Route Reply (RREP) that travels along the reverse path set up by RREQ. AODV is based on the shortest path between two nodes in an ad hoc network plane and does not support QoS features.

3.3 QoS

In contrast, QoS AODV by considering quality-of-service (QoS) finds the best route that satisfies the end to-end QoS requirement. In fact, QoS-AODV modifies the route discovery and maintenance mechanisms of AODV to provide QoS assurance. A QoS extension for AODV routing packets was proposed in (Chen Niansheng et al., 2004). This QoS object extension includes the Minimum bandwidth or Maximum delay parameters of each application, and it also has a "session ID" which is used to identify each QoS flow that is established according to the application. The extensions are added to the route messages (RREQ, RREP) during the phase of route discovery. A node which receives a RREQ with a quality of service extension must be able to meet the service requirement in order to either rebroadcast the RREQ, or uncast a RREP to the source. The maximum delay used in RREQ indicates the maximum time allowed to be used for a transmission from the current node to the destination and the minimum

bandwidth extension specifies the minimum amount of bandwidth that must be made available along an acceptable path from the source to the destination.

As we seen above, it is addressing the quality of service requirement of the network nodes but it does not ensure the energy of a node is considered for routing algorithm. Though it may have many dead cells, not be considered for routing because of stability and dead battery, but still we have many mobile nodes are below average battery power life. These nodes will also participate and considered for routing and it causes sudden dropping of data packets during transmission stage. So to avoid this situation we are partitioning the route formation algorithm in two different phases. 1. Route requests with reverse route formation and 2. Route response with data transmission.

4. Hexagonal Configuration and Routing

They are many routing algorithms considered over rectangular grids for finding a shortest path in a network as rectangular gird does not give better tessellation as it gives variable distance between the grids .In this proposal we have partitioned the whole network plane into hexagonal grids as shown in the Figure 2 to give better tessellation of nodes in a network. There have been many articles (Chen, Li., 2004), (Fayas Asharindavida et al., 2012) showing that usage of hexagonal grid gives us a better configuration of network topology with higher communication links



Figure 2. Basic Model of hexagonal cell (Hexagonally Partitioned Cellular Automata).

despite failures of links in a network. It is widely used in image processing (Fayas Asharindavida et al., 2012), gaming and other spatial applications (K. Sahr, 2011). The primary advantage of hexagonal grids over a traditional square grids is that the distance between the center of each hexagonal grid and the center of all six adjacent hexagonal grids are constant.

The topology (Figure 2.) defines how to configure a hexagonal network to route the information through hexagonal grids. Each node in a network is mapped into the cells and states are assigned for each node. Then finally the basic AODV topology is applied to find a shortest path with two phase algorithm. In the first phase algorithm assigns wave marks to each grids and in the second phase of the algorithm finds a path with constrains assumed. Before we get into two phases of routing, we introduce notions for cellular automata over hexagonal grid similar to square grid¹.

4.1 Hexagons and its States Consideration

First step is to divide the whole plane into hexagonal partitions and then assign states for the each cell; states of a node will be changed according to neighbors' states. As shown in the Figure 2, the whole network plane is partitioned into regular hexagonal grid and cells parallel to the x, y axis. The coordinates inside cells indicates geometric position of each node in a plane and hexagonal grid corresponds to mobile node in an ad-hoc network. Each cell in our configuration contains six neighbors and the next state of current cell is determined by current state as well as the states of six neighbors' states. A total plane (surface) is partitioned into hexagonal cells as north-east, east, south-east, south-west and north-west in Figure 3 state changes in a cell and its neighbor's states as an input to a centralized cell². There are 18 (Figure 5 and 6) states considered for assigning each hexagonal grid" "There are 18 (Init_S, Dead, DR, Init_D, WLD, WRD, WLU, WR, WL, PRU, WRU, PLU, PLD, PRD, PL, PR, Found (des_ Found), Flush) possible states (Figure 5 and 6) considered for each node in a hexagonal cell and it will be used for routing between nodes in a network. These predefines states are randomly used for configuring execution of routing process.

4.2 Configuration of Hexagonal grids

Definition: A deterministic six neighborhood cellular automaton H over a hexagonal grid is defined by



Figure 3. Neighbors representation of a hexagonal cell.

H= (Q, δ , Init_S) where Q is defined in the expression (4) (3)

Q= {Init_S, Dead, DR, Init_D, WLD, WRD, WLU, WR, WL, PRU, WRU, PLU, PLD, PRD, PL, PR, Found (des_Found), Clear} (4)

Here δ is a function from Q^7 to $Q [Q^7$ the tuple having 7 states with first component being current state and rest being six neighborhood states.

Init_S indicates start state of H des_Found indicates the final state.

A configuration over the set $Q = A \times B \times C \times D \times E \times F$ is mapping α : $Z^2 \rightarrow Q$. Let Conf (Q) denotes the set of all configurations over Q, i.e., Conf (Q) = { α / α : $Z^2 \rightarrow Q$ }.

In the following, an equations δ (a, b, c, d, e, f) = (a', b', c', d', e', f') depicted in Figure 2 is called a rule of H. a', b', c', d', e', f' are changed its states by the cellular automata.

Configuration of these hexagonls (Kenichi Morita, et al.) is nothing just assigning wave symbols into the cells as seen in the section IV (C). In our Proposed model there are six neighbors and $2^{6} = 64$ rules will be considered for its transition of a single cell.It states that we will be having 64 transition rules that can be apllied to change state of a hexagonal grid.Totall

we have 18 states for six neighbors and these 18 states should be configured in the process of finding a shortest path between two mobile nodes. These six negibors are considered as given in the Figure 3.

4.3 Routing through hexagonal grids

In order to find a path with adequate QoS between two communicating nodes in the network we consider delay and energy as the QoS constraint. We have assumed two dimensional network plane consisting of many number of mobile nodes spread randomly and this plane is partitioned into hexagonal grids having each node with six neighbors.

There is no hierarchy between nodes, and the network plane is homogeneous (all nodes have the same properties). Every node represents a cell of the cellular automaton. As the Figure 4 shows data movement between two cells represents one hop and each cell has a state which corresponds to states of its neighbor nodes that it is surrounded. The network plane also contains dead cells through which communication cannot take place. These cells represent physical obstacles (such as a high-rise building) or simply the absence of a communication link. Two nodes with a dead cell between them cannot communicate directly to each other. As network nodes can move randomly to any of the neighboring cells the Moor neighborhood will be used for mobility.

4.4 Route Construction

In our method, for discovering a QoS path that satisfies the delay-constraint and energy-constraint as the QoS parameters in addition it may be applied to bandwidth, the source node broadcasts QRREQ message with the delay requirement of the connection request (maximum delay (Dmax)) and maximum energy (Emax), to its communicating neighbors which includes, all the nodes on its top, down, left and right side. According to lee algorithm, at first, the nodes which are in neighborhood of the source node become wave. But for providing a delay-constraint Dmax and energy constraint Emax must be first



Figure 4. Routing through hexagonal cells.

subtract from NODE-TRAVERSAL-Time (NTT) and (NED) NODE-ENERGY(NED)-Data (power required to transfer available data) in every intermediate node before becoming as a wave node. Therefore two conditions may be happened:

- If the NTT is greater than the maximum (remaining) delay in delay field and NED is less than the energy in energy field of QRREQ, the intermediate node must drop the QRREQ, and don't become a wave node.
- 2. If the NTT is less and NED is greater than the maximum delay in message and maximum energy in message, by subtracting from its value of the NTT and NED, the intermediate node will become wave nodes and continue broadcasting the RREQ³.

As depicted in the Figure 4 that describes how a route construction is happening by using hexagonal grids, phase1 constructs wave marks when a node broadcasts route request to its neighbors⁴. Though it creates multiple paths for a single request, it only considers a request which reaches to destination node at first that will be declared as an optimal path. The wave nodes re-broadcast the message to their neighbors, and set up a reverse path to the sender, which is represented with pointing arrows. This process continues until the message reaches the destination node or the delay experienced by the packet exceeds the limit Dmax and Emax. Since there is more than one path from the sender to the destination, the destination may receive multiple QRREQ message for the same sender. However, the route through which the destination node receives the QRREQ message first is the shortest path between the sender and the destination which guarantees the Quality assurance, thus the destination replies to the first QRREQ message by sending a QRREP message using the reverse path set up when the QRREQ messages are forwarded^{5,6}. All the wave nodes that lie on this route between the source and the destination become the *path* nodes. All communications between the source and the destination from this point onwards takes place using this path until the topology of the network changes. All other wave nodes that don't see a path node in their neighbor pointing towards them are sent a clear state message to move them from the *wave* state to a *clear* state⁷.

4.4.1 Phase 1: Wave Mark Assignment

Let the set of states be Q and the elements of Q are described as follows:States considered for routing

are Init (initial state of each node except source and destination), Dead (Dead Cell), Init_S (Initial State of the Source node), Init_D (initial state of the destination), DR (Destination Ready; state of the destination node after it has received a RREQ message), WLU (Wave Left Up), WLD (Wave Left Down), WRU(Wave Right Up), WRD(Wave Right Dow n), WR (Right), WL (Left), PRU (Path Up), PRD (Path Down), PLU (Path Left Up), PLD (Path Left Down), PR (Path Right), PL (Path Left), Flush/Clear (Fs) (final state of the node that received a wave message but is not going to become a path node) Found (route found; final state of the Source node).The Figure5 and Figure6 represents the possible states that can be assigned to a hexagonal grid. As we early told that this wave marking process is carried out by the phase1 of the algorithm⁸.

4.4.2 Phase 2: Routing using Wave Marks

After assigning these wave marks, routing process will be carried by sending data through the marking notations. Once a path is declared by the route response message, destination node identifies its nodes to transfer the data. Route response message appends IDs of mobile nodes along the way it traversed to the source node. Now the source node identifies some set of nodes' ID to reach the destination in last amount of time. These two phases are given as an algorithm in the following section⁹.

5. Route Finding Algorithm

Following algorithm1 describes to find a path between two nodes in an ad-hoc network.

5.1 Algorithm Description

Given a network, mapped into hexagonal cells, each node in a network viewed as a hexagonal cell .Finding neighbor of a cell, the system uses six different directions like east, west, north, south, south-east, south-west, north-east, north-west. For each node in a cell we have to define a state for that totally we have considered 18 different states among this one is assigned to a cell accordingly¹⁰.

Source node is defined as Init_S, destination node is defined as Init_D and all other cells are initialized as Init except dead cells. Now routing occurs by using these 18 states in two phases. In phase1, called as wave mark assignment, as given in the Algorithm1 location of the source node Init_S is indicated H[X,Y]. Hexagonal node H broadcast Routing Request (RREQ) with energy(Emax) and delay(Dmax) constrains, cellular automaton in the each node chooses a neighbor by NextH[X,Y]=CA(H[$X_{n=1}, Y_{n+1}$]) based on these two constrains. Along the way it creates the path between source and destination by assigning wave marks by using the function Assign_waveMarks ().

Once it reaches its destination node address which is appended with the Route Request H[X,Y], the first RREQ to destination is considered for finding its traversed to declare as an shortest path. Each time the route request reaches to its neighborhood node; the condition if(D_addr=Dest_Node_addr) will be checked to find the destination node's address which is equal to the RREQ's current address. In phase 2, called as routing through wave marks, response will be given through RRES message by GenRResp() function and it appends the node traversed ids to route a response message to the source node^{11,12}. For sending response it follows a path the broadcast used to carry RREQ message to reach the destination node at first in a given time will be chosen. Finally the state Init_S will be turned into Found and Init_D will be turned into DR Writhen data transfer will be taking place. All other cell states turned to clear for the next routing execution. The basic and detailed architecture is depicted in Figure 7 and 8.



Figure 5. Indentifying states in Phase1.



Figure 6. Indentifying states in Phase2.



Figure 7. The Basic Architecture.



Figure 8. Detailed Architecture.

5.2 Architecture Diagram

The Figure7 and 8 depicts architecture of a model that will be followed to identify a shortest path in a hexagonally partitioned grid network. The Figure 7 shows a basic architecture to make understand some preliminary steps to be performed and it is redrawn to give detailed architecture as in Figure 8.

5.3 Routing Procedure

Step 1: Map the nodes in a network into the hexagonal grids.

The algorithm works as following ...

Step 2: Apply basic algorithms such as Modified

Alogrithm1:

Route Discovery Algorithm:

Input: H[X, Y], $H[X_n, Y_n]$ /Location of the source and Destination grid.

Dmax, Emax /Delay and Energy Constraints.

S_addr, D_addr/Ip, N [M] address of source and destination node and its mobility

Output: Route $[N][X_i, Y_i]$

I. Finding next hop node by using Check function.

NextH[X, Y] =Check (N [M], Emax, Dmax)/ Neighborhood node which has less mobility.

II. Wave Marking.

Broadcast (RReq [S_addr, Broacast_id, D_addr, Nexthop]);

If (H $[X_{i,}Y_j]$ <Dmax && H $[X_{i,}Y_j]$ >Emax)/Checking for delay and energy constraints.

Assign_WaveMarks (DR, Init_D, WLD, WRD, WLU, WR, WL, PRU, WRU, PLU, PLD, PRD, PL, PR);

Else

H $[X_{n+1}, Y_{n+1}]$ /Check for the constraints in another neighborhood node.

If(RReq(D_addr=Dest_Node_addr) Then

Dest_Node_State=Found; /All other nodes' sate will be Clear except that the

RRequest traversed path.

End if:

End if:

III. Backtracking.

If (RReq(D_addr=Dest_Node_addr) Then GenRResp (N, D_addr, S_addr)/Generates Route Response and it will be sent to the destination node through $N=n_{k,}n_{k-1},n_{k-2}...n$ (Source node). Else Rebroadcast (); End if: H[X, Y] =Transmit(data);

Lee's algorithm and AODV protocol.

- Step 3: Implement AODV protocol for accessing nodes information in a network, as it sends and receives route request and route response to and from the mobile nodes.
- Step 4: Broadcast AODV the route to all nodes in a network with energy and delay constrains through neighbors of a hexagonal grid.
- Step 5: Assign wave marks as described in modified Lee's algorithm to identify the route request traversed path and to do the backtracking.
- Step 6: Check for the constraints in each neighborhood grid if it is less than the margin then it will move to another neighborhood grid else the state of a grid is changed by the cellular automata.
- Step 7: Repeat the steps 4 and 5 until it finds the destination node.
- Step 8: Declare a shortest route in which the request that reaches to the destination node at first by accumulating timestamp values.
- Step 9: Send a route request message to the source node, it contains nodes' id to reach destination node quickly.
- Step 10: Follow the wave marks constructed/assigned for that route identified as a shortest one to do the transmission of data packets.

6. Simulation Model

As Figure 9 shows the basic topology of network model is done by using C and the matrix output shows its execution of our proposed routing algorithm. The diagram Figure 9 shows the mapping of hexagonal grids into a matrix format. Each element in a matrix represents hexagons' states (nodes' state); it would be assigned during the first phase of routing. Movement of nodes in a network happens hexagonally to its respective six neighbors. As indicated in the figure, the destination node (INIT_D) and the source node (INIT_S) will move to the south-west and southeast, respectively. It's obvious that the dead nodes which are represented as DEAD notations are static and didn't change their location after the topology of a network makes changes. For each neighborhood selection Cellular automaton is used to select the best nearest node with

Initial Distribution

DEAD INIT INIT DEAD INIT INIT	DEAD INIT INIT INIT INIT DEAD	INIT INIT DEAD INIT INIT INIT_S	INIT INIT INIT INIT INIT SDEAD	INIT_I INIT INIT INIT INIT DEAD	DEAD INIT INIT DEAD INIT INIT
Time DEAD INIT INIT DEAD INIT INIT INIT	Step1 DEAD INIT INIT INIT WRD DEAD	INIT INIT DEAD INIT INIT INIT_S	INIT INIT INIT INIT WRU SDEAD	INIT_I INIT INIT WLD INIT DEAD	D DEAD INIT WLD DEAD INIT INIT
Time s DEAD I INIT I INIT I DEAD I INIT V INIT I	tep2 DEAD IN NIT IN NIT D NIT W WRD IN DEAD IN	VIT IN VIT IN EAD WI VID IN VIT WI VIT_S DI	IT INI IT WR RU INI IT WL RU INI EAD DE.	T_D DE. D INI I WL D DE. I INI AD INI	AD T D AD T T
Final D DEAD CLEAR CLEAR DEAD CLEAR CLEAR	Networ DEAD CLEAR INIT INIT WRD DEAD	k Statu INIT CLEAR DEAD WLD INIT FOUND	PRD CLEAR WRU INIT PRU DEAD	DR PRD INIT PLD INIT DEAD	DEAD INIT WLD DEAD CLEAR CLEAR

Figure 9. grid matrix.

best energy level and controlled mobility. The Figure 9 also shows that the routing mechanism is performed well as the path with adequate route is discovered. Our proposed routing protocol with the help of hexagonal cellular automaton doesn't need to store accumulated delay for calculating the delay in phase of unicasting RREP instead of QoS-AODV, by defining only constant set of states. We consider a hexagonal grid network of 500m×500m of mobile nodes placed randomly in the area¹³.

Our simulation is conducted at different pause times and speeds .We have to vary the pause time from 0 to 800 seconds which is chosen to be between high mobility rate (pause time 0 seconds) and no mobility (pause time 600seconds), and changes would be studied on the performance of the routing protocols. The average node speed in this group of simulations is chosen to be 6 m/s and node speeds are 5, 10, 15, 20 m/s. The pause time for these scenarios is 60seconds. Delay constraints are chosen to be 0.1 and 0.3 seconds and finally energy constraint is set based on network behavior. Performance of the system is compared with AODV and the original QoS-AODV protocol¹⁴.

7. Conclusion

Lee Routing algorithm over rectangular grid is extended to hexagonal grid successfully in this paper. The single hop hexagonal cellular automata have been studied for constructing a shortest path in an ad-hoc network as it is based on AODV routing. And this routing algorithm ensures quality of service by taking bandwidth and delay constraints as QoS parameters with optimized use of resource. Hence the variant of Lee routing algorithm for finding the shortest path using hexagonal cells is established and implemented with simulation tool like NS2. This can be extended to non uniform types of grids like semi-regular grids.

8. References

- Ghalavand A, Khademzadeh A, Dana A, Ghalavand G. A Routing Algorithm Based on Cellular Automata for Mobile Ad-hoc Networks. 2011 Sep; 8(5).
- Udayakumar R, Khanaa V, Kaliyamurthie KP. High data rate for coherent optical wired communication using DSP. Indian Journal of Science and Technology. 2013; 6(S6):4772-6. ISSN: 0974-6846.
- Abbas AM, Kure O. A Quality of Service in Mobile Ad- hoc Networks: A Survey. IJAHUC. 2010 Jun; 6(2):75–98.
- Kumar SS, Rao RKM, Kumar DR, Panwar S, Prasad CS. Biocontrol by plant growth promoting rhizobacteria against black scurf and stem canker disease of potato caused by *Rhizoctonia solani*. Archives of Phytopathology and Plant Protection. 2013; 46(4):487–502. ISSN: 0323-5408.
- 5. Colin PD, Sander BP, Oom, Beecham JA. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. 2007.
- 6. Udayakumar R, Khanaa V, Kaliyamurthie KP. Optical ring architecture performance evaluation using ordinary

receiver. Indian Journal of Science and Technology. 2013; 6(S6):4742-7. ISSN: 0974-6846.

- Niansheng C, Layuan L. Research on the Basis of QoS Routing Protocol of Ad Hoc Network, DCABES 2004. Proceedings Wuhan: Hubei Science and Technology Press; 2004. p. 206–10.
- Palaneeswari SM, Rajan ASPM, Jothimalar SS. Blood lead in End-Stage Renal Disease (ESRD) patients who were on maintainence haemodialysis. Journal of Clinical and Diagnostic Research. 2012; 6(10):1633–5. ISSN: 0973-709X.
- 9. Asharindavida F, Hundewale N. Study on Hexagonal Grid in Image Processing. Saudi Arabia: Stultan Aljahdali Taif University; 2012.
- Udayakumar R, Khanaa V, Kaliyamurthie KP. Performance analysis of resilient architecture with protection mechanism. Indian Journal of Science and Technology. 2013; 6(S6):4737–41. ISSN: 0974-6846.
- Hochberger C, Hoffmann R. Solving routing problems with cellular automata. Proceedings of the Second conference on Cellular Automata for Research and Industry; Milan, Italy. 1996.
- Johnson DB, Maltz DA. Dynamic Source Routing in Ad-hoc Wireless Networks, Kluwe. Universality of Reversible Hexagonal Cellular Automata; 1996.
- Perkins E, Royer. Quality of Service for ad-hoc On-demand Distance Vector Routing in Zntemet draft. 2003 Oct. Available from: http://www.httpcharliep/txt/aodvid/qos. txt
- 14. Park V, Corson MS. A highly adaptive distributed routing algorithm for mobile wireless network. Proceedings of the 1997 IEEE INFOCOM; Kobe, Japan. 1997 Apr. p. 1405–13.