Table 4 Node n_{16} and its neighbors' three-dimensional coordinates.

currentNode Address	neighborMainAddr	xpos	ypos	zpos	distance
10.1.1.16	10.1.1.14	1673	905	1296	617.6412
10.1.1.16	10.1.1.17	1887	1284	1890	677.8175
10.1.1.16	10.1.1.11	1643	1634	1073	395.7857
10.1.1.16	10.1.1.2	1213	1052	1400	498.7644
10.1.1.16	10.1.1.3	1150	977	1682	661.8442

3 The Localization for the 2-hop Neighbor Nodes

A 2-hop neighbor which is not the node itself or a neighbor of the node, and in addition it is a neighbor of a neighbor, with willingness different from WILL_NEVER, of the node. In order to enable the node to save the location information of its 2-hop neighbors, the format for 2-hop Neighbor Set (TwoHopNeighborSet) is modified, three fields are added, which is shown in the following code. xpos, ypos and zpos specifies the 2-hop neighbor node's position expressed in three dimensional coordinates, twoHopNeighborAddr is the main address of a 2-hop neighbor with a symmetric link to neighborMainAddr, and expirationTime specifies the time at which the tuple expires and should be removed.

```
struct TwoHopNeighborTuple
{
  uint32_t xpos;
  uint32_t ypos;
  uint32_t zpos;
  Ipv4Address neighborMainAddr;
  Ipv4Address twoHopNeighborAddr;
  Time expirationTime;
};
```

The link sensing begins after the node receives the HELLO message, and the maintenance is carried out for the TwoHopNeighborSet according to the information getting from the hello message. The acquisition and update process for 2-hop nodes' position information is as follows:

(1) If the TwoHopNeighborTuple doesn't exist in the TwoHopNeighborSet, it is inserted into the TwoHopNeighborSet, and the location information for the 2-hop nodes is from the HELLO message.

(2) If the Tuple already exists, owning to the location information for the 2-hop node might have been changed since the last HELLO (which including the location information about this 2-hop node) message is received, the corresponding TwoHopNeighborTuple in the TwoHopNeighborSet should be updated using the information from the HELLO message.

(3) Due to the network topology changes dynamically or other reasons, some tuples in TwoHopNeighborSet may be not valid along the time goes by, this kind of tuples should be removed from the 2-hop neighbor information base according to the information getting from the hello message.

In order to verify the node localization accuracy for 2-hop neighbors, using the same simulation topology which is shown in Fig.1 above, and the simulation parameters are also set in common. Let the locations of each nodes remain stationary, verify node localization accuracy of the 2-hop neighbor, and the result is showed in Fig.3.

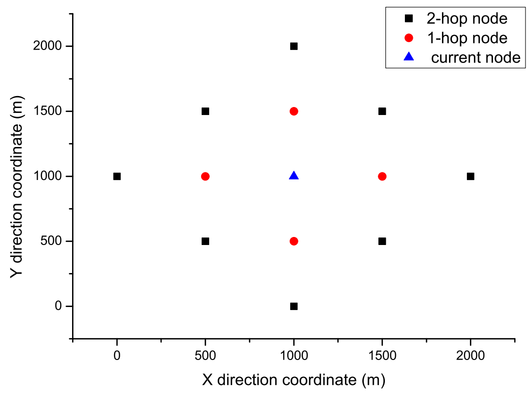

Fig. 3. The locations of 2-hop nodes.

n_{13} is selected as the reference node, and the locations of its neighbors and 2-hop nodes are analyzed. The red points are its 1-hop neighbors, and the black points represent its 2-hop nodes. According to the Fig.1, it is clearly to show that n_{13} can locate its 1-hop and 2-hop nodes precisely when all the nodes in the network remain motionless.

In order to verify the node localization accuracy for 2-hop nodes when the nodes in MANET move randomly, the above experimental environment is modified. Within a 2000m * 2000m rectangle area, there are 25 nodes, RandomDirection2dMobilityModel is used in the entire network, and the distribution for these 25 nodes is randomly in the above space as well. n_{13} is also selected as the reference node, and the locations of its neighbors and 2-hop nodes are analyzed. At some point, the neighbors' location is showed in fig.4, and fig.5 is the 1-hop and 2-hop nodes' distribution. The results shows that because of the nodes moving frequently, some of the locations for one or two hops nodes are already out of date, also some records in NeighborSet and TwoHopNeighborSet are not valid owning to the moving of the nodes in the network.

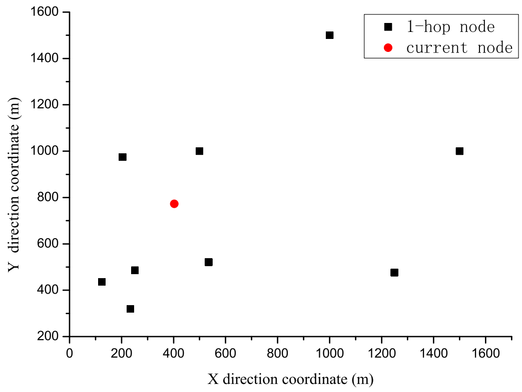

Fig.4. The locations of the neighbors.

4 The Localization for the mul-hop Meighbor Nodes

Beside one and two hop nodes, there are many other multi-hop nodes which need to be located in the network. In order to enable the node to save the location information of its mul-hop neighbors, the format for the topology set (TopologySet) is modified, three fields are added, which is shown in the following code. xpos, ypos and zpos specifies the multi-hop neighbor node's position expressed in three dimensional coordinates, and destAddr is the main address of a node, which may be reached in one hop from the node with the main address lastAddr. Typically, lastAddr is a MPR of destAddr. sequenceNumber is a sequence number, and expirationTime specifies the time at which this tuple expires and must be removed.

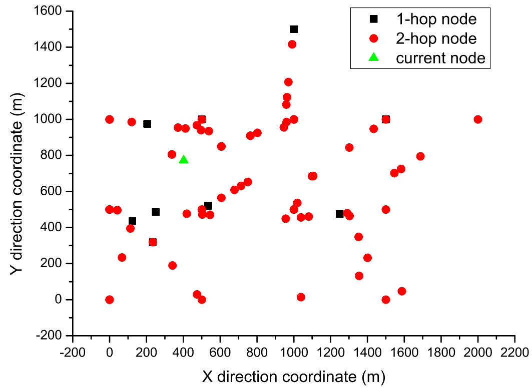

Fig.5. The locations of one or two hop nodes.

```
struct TopologyTuple
{
 uint32_t xpos;
 uint32_t ypos;
 uint32_t zpos;
 Ipv4Address destAddr;
 Ipv4Address lastAddr;
 uint16_t sequenceNumber;
 Time expirationTime;
};
```

Table 5. The TC message with three-dimensional coordinates.

ANSN	Reserved
Advertised Neighbor Main Address	
xpos	
ypos	
zpos	
Advertised Neighbor Main Address	
xpos	
ypos	
zpos	
…	

Each node in the network maintains topology information about the network. This information is acquired and updated by periodically sending the TC-messages. It contains at least the links of its MPR Selector set (the neighbors which have selected the sender node as a MPR) and can be used for routing table calculations. The three-dimensional coordinates for MPR Selectors are added in the TC message so as to implement the localization for the mult-hop nodes. The TC message with three-dimensional coordinates for the MPR Selectors is showed in Table 5.

Upon receiving a TC message, the TopologySet then is updated as follows:

(1) If the message is generated or forwarded by the sender interface which is not in the symmetric 1-hop neighborhood of this node, or it is the duplicated message which has been received multiple times, or it is already obsolete in this node, the message should be discarded or deleted.

(2) The message should be forwarded, if this message is from the sender interface which is in the MPR Selector set of this node.

(3) Otherwise, the TopologySet should be updated according to the advertised neighbor main address received in the TC message

In order to verify the node localization accuracy for the multi-hop neighbors, the experimental environment is just like Fig.1. The location of each node remains stationary, and the node localization accuracy is verified. The positions of the multi-hops nodes from the TopologySet in n_{13} are displayed in Fig.6, and it shows that the multi-hop nodes can be located accurately when the nodes remained stationary.

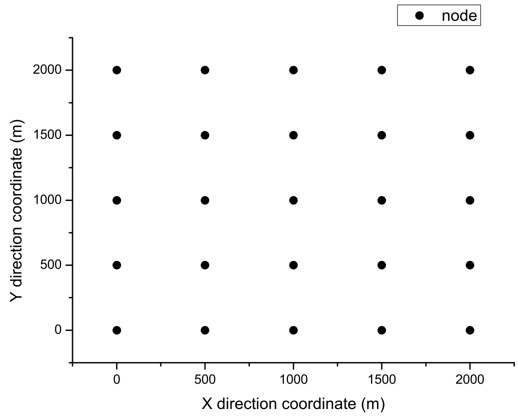

Fig.6. The locations of multi-hop nodes (static).

The RandomDirection2dMobilityModel is used for all the nodes, and all the nodes in the network move at spend of 25m/s. The experiment result of the node n_{25} (IP address, 10.1.1.25) is selected to analyze the positions of the multi-hop nodes in the network. In Fig.7, it shows that more than one path can reach the multi-hop destination node from the current node n_{25}, because these paths is worked out by its different neighbors, this causes the position for each multi-hop node have many different values, and it also reflects that the precise localization is very difficult when the nodes move randomly.

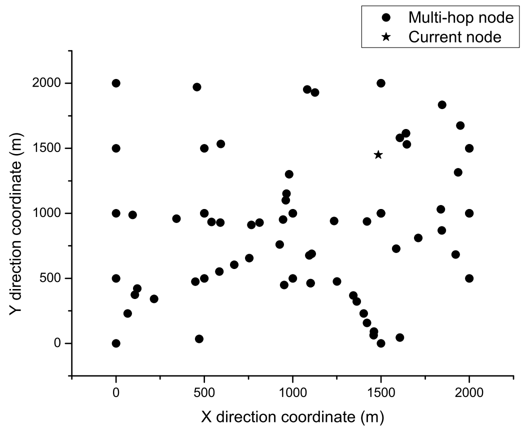

Fig.7. The locations of multi-hop nodes (moving).

5 Realize Localization in Routing Table

Each node maintains a routing table which allows it to route data, destined for the other nodes in the network. In order to save the three dimensional position information in the routing table, the storage structure for RoutingTableSet is changed, which is shown in the following code. xpos, ypos and zpos specifies the destination node’s position expressed in three dimensional coordinates, the node identified by destAddr is estimated to be distance hops away from the local node, that the symmetric neighbor node with interface address nextAddr is the next hop node in the route to destAddr, and that this symmetric neighbor node is reachable through the local interface with the address interface.

```
struct RoutingTableEntry
{
  uint32_t xpos;
  uint32_t ypos;
  uint32_t zpos;
  Ipv4Address destAddr;
  Ipv4Address nextAddr;
  uint32_t interface;
  uint32_t distance;
};
```

The routing table is recalculated in case of neighbor appearance or loss, when a 2-hop tuple is created or removed, when a topology tuple is created or removed or when multiple interface association information changes. The position information recorded in NeighborSet, TwoHopNeighborSet and TopologySet is used by current node for the routing table calculation, and the procedures to calculate (or recalculate) the routing table is as follows:

(1) All the records from the routing table are removed. The new routing records are added starting with the symmetric neighbors (h=1) as the destination nodes according to the NeighborSet, and also the position information for these paths in the routing table is from the NeighborSet.

(2) The new routing records for 2-hop paths are added or updated according to the TwoHopNeighborSet, and the position information in the TwoHopNeighborSet is used for these 2-hop paths in the routing table.

(3) The new routing records for multi-hop paths are added or updated according to the TopologySet, and also the position information for these multi-hop paths in the routing table is from the TopologySet.

The experimental topology is just like Fig.1, The position of each node remains stationary, and it is used to verify the localization accuracy for the destination nodes in the routing table. The results show that when the nodes in the network remain static, the current node can easily get position information for every other node in the whole network by using the Routing Table.

At the same time, we make use of the RandomDirection2dMobilityModel to testify the localization accuracy for the destination nodes in the routing table, the speed of the mobility model is 25m/s. The node n_{25} is selected for data analysis. The results also show that the current node can easily get position information for every other node in the whole network.

After the changes above, every node which uses the modified OLSR protocol as the routing protocol can easily get the position information of other nodes in the whole network. The distribution for 1-hop, 2-hop and multi-hop nodes can also be analyzed from the position information, and the relevant data is provided to calculate the density of nodes in the network as well.

The RandomDirection2dMobilityModel is used in every node in the whole network, and the speed of the mobility model is 10m/s. The node n_{25} is selected for data analysis, and it shows that the number of destination nodes of the routing table in current node n_{25} is changing timely which is display in Fig.8.

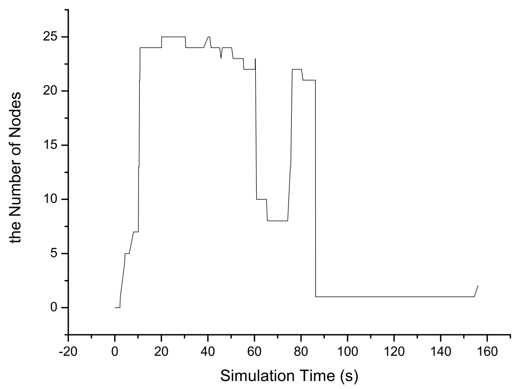

Fig.8. The number of destination nodes of the routing table in node n_{25}.

6 The Performance Analysis for the Localization Algorithm

Node can achieve the positions of other nodes in the Ad Hoc network based on the algorithm described above, the localization is based on the OLSR routing protocol, the function for localization is added to the original OLSR protocol, and it can be Located in the OLSR protocol, referred to as L-OLSR. A series of simulation experiments are carried out to analyze and compare the performance for L-OLSR and OLSR protocol. Table 6 shows the experimental parameters.

Table 6 Simulation parameters.

Modulation	802.11b
Area	2000m * 2000m
Nodes	⩽50
Mobility Model	ConstantPositionMobilityModel
Simulation Time	500s
Traffic Sources	⩽50
Traffic Type	CBR
Packet Size	1024 bytes

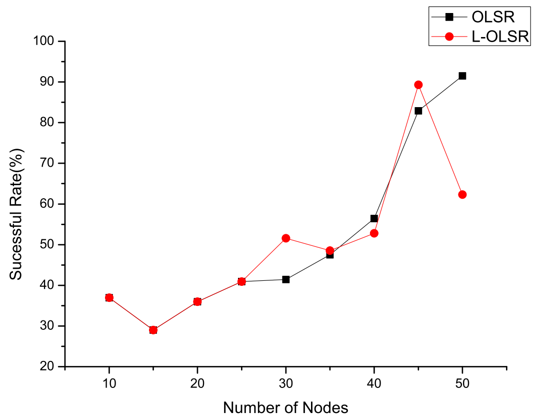

Fig.9. Delivery success rate (DSSS 1M).

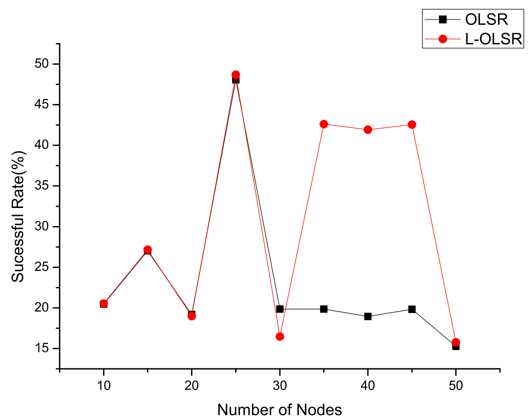

Fig.10. Delivery success rate (DSSS 2M).

The layout of the nodes in simulation environment is as follows, the horizontal and vertical distances between two nodes are both 600m, all the nodes keep stationary during the whole simulation. The node sends a data packet every one second, and totally 1500 data packets are sent during the period of the simulation. The number of the nodes in the simulation starts from 10, and it gradually increases every 5 to 50. The average success rate for the delivery data packets is work out for all the nodes.

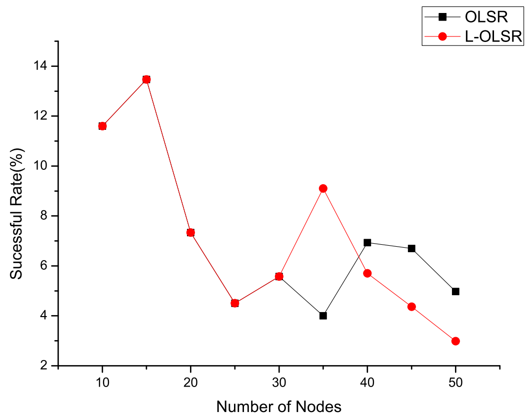

Fig.11. Delivery success rate (DSSS 5_5 M).

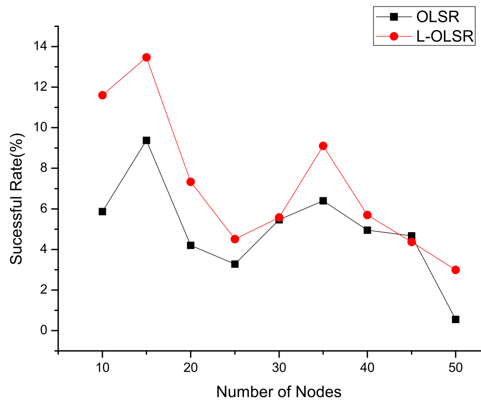

Fig.12. Delivery success rate (DSSS 11 M).

Fig.9, Fig.10, Fig.11 and Fig.12 are the success rate for the delivery data packets when all the nodes keep static during the whole simulation, the 802.11b is used in the simulation, and the number of nodes in the network changed dynamically. The packet delivery success rate for both L-OLSR and OLSR protocol changes dynamically with the increase in the number of nodes, and moreover, it presents the instability.

Although the localization function is added in L-OLSR based on the OLSR protocol, but its performance is very close to the OLSR, and in some cases, even better than the original protocol.

The following simulation is the analysis of the performance between the L-OLSR and OLSR protocol when the nodes in the network move randomly, the horizontal and vertical distances between two nodes are both 600m, all the nodes keep moving randomly during the whole simulation. The node sends a data packet every one second and totally 150 data packets are sent in the period of the simulation. The number of the nodes in the simulation starts from 10, and it gradually increases every 5 to 50. The average success rate for the delivery data packets is work out for all the nodes. The other parameters are given in the Table 7.

Table 7 Simulation parameters.

Modulation	802.11b
Area	4000m * 4000m
Nodes	≤50
Mobility Model	RandomDirection2dMobilityModel
Simulation Time	500s
Traffic Sources	≤50
Traffic Type	CBR
Packet Size	1024 bytes

Fig.13 is the success rate for the delivery data packets when all the nodes moving randomly according to the RandomDirection2dMobilityModel during the whole simulation, the 802.11b is used in the simulation, and the number of nodes in the network changed dynamically. The packet delivery success rate for both L-OLSR and OLSR protocol changes dynamically with the increase in the number of nodes, and moreover, it presents the instability. It also shows that the performance of L-OLSR is very close to the OLSR. [12, 13]

Another simulation is carried out to verify the distance impact on the performance for the L-OLSR and OLSR protocol. The layout of the nodes in simulation environment is as follows, the 16 nodes are distributed in a 4*4 network. At the beginning, the horizontal and vertical distances between two nodes are both 50m, all the nodes moving randomly during the whole simulation. The node sends a data packet every one second and totally 150 data packets are sent during the period of the simulation. The distance between the every two nodes in the simulation starts from 50m, and it gradually increases every 50m to 350m. The average success rate for the delivery data packets is work out for all the nodes.

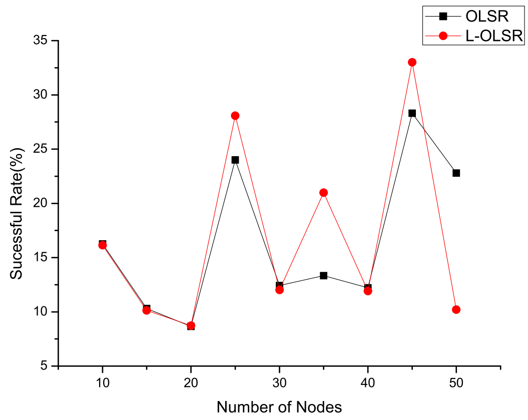

Fig.13. Delivery success rate (DSSS 11 M).

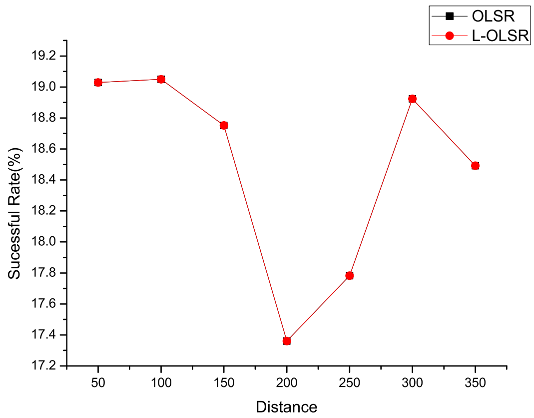

Fig.14. Delivery success rate (DSSS 11 M).

In Fig.14, it shows that when all the nodes move randomly and the distance between the every two nodes increases gradually during the whole simulation, the packet delivery success rate for both L-OLSR and OLSR protocol changes dynamically, but it shows that the performance of success rate for L-OLSR and OLSR is identical.

7 Conclusion

Along with the fast development of the wireless Ad Hoc network, it has become an important branch for the mobile communication technology. In many applications in wireless Ad Hoc network, it is one of the important conditions to accurately learn the node's positions, and therefore, the wireless node's localization technology has received more and more attentions. The node in wireless Ad Hoc network moves randomly, Thus it causes the node's position is also stochastic. The node localization technology is one of the important technical in applied researches for the wireless Ad Hoc network. In this paper, we propose that the wireless Ad Hoc network node knows its position (three-dimensional coordinates, through the node equipped with a GPS or other positioning devices), based on the OLSR routing protocol in wireless networks, we try to let the node to achieve the precise positions of its surrounding nodes or the entire wireless Ad Hoc network nodes, in addition, the OLSR routing protocol which has localization function is analyzed.

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References

1. X.M.GU, H.Q.CAO, and S.SHI, "Localization arithmetic based on directions in ad hoc network," COMPUTER ENGINEERING AND APPLICATIONS, vol. 47, no. 7, pp. 155–157, Jul 2008.
2. A.Savvides, W.Garber, and S.Adalkha, "On the Error Characteristics of Multihop Node Localization in Ad-Hoc Sensor Networks," in 2nd International Work-shop on Information Processing in Sensor Networks, Apr 2003, pp. 22–23.
3. V.Reino, "Localization in Ad-Hoc Sensor Networks," http://users.tkk.fi/virranko/localization_report.pdf, Feb 2010.
4. Y.Wang, T.Liang, X.Yang, and D.Zhang, "Scalable and Effective Cluster Based Routing Algorithm Using Nodes' Location for Mobile Ad Hoc Networks," Information Technology Journal, vol. 7, no. 7, pp. 958–971, Jul 2008.
5. M.A.Bhagyaveni and S.Shanmugavel, "Multicast Routing for Mobile Ad Hoc Network Using Diversity Coding," Information Technology Journal, vol. 4, no. 2, pp. 176–183, Feb 2005.
6. L.Zhetao and L.Renfa, "Survey of Geographical Routing in Multimedia Wireless Sensor Networks," Information Technology Journal, vol. 10, no. 1, pp. 11–15, Jan 2011.
7. I.A.Khan and E.Y.Peng, "Angle-aware broadcasting techniques for wireless mobile ad hoc networks," Information Technology Journal, vol. 7, no. 7, pp. 972–982, Jul 2008.
8. C. L.Hsien and J.L.Cheng, "A position-based connectionless routing algorithm for manet and wimax under high mobility and various node densities," Information Technology Journal, vol. 7, no. 3, pp. 458–465, Mar 2008.
9. S.Sachin, "P-OLSR: Position-based optimized link state routing for mobile Ad Hoc networks," in LCN2009: The 34th IEEE Conference on Local Computer Networks, Oct 2009, pp. 237–240.
10. Q.H.YU, "Research on Localization Technique in Ad-hoc Network," Xian Electronics Science and Technology University. Master thesis, pp. 29–30, Jan 2005.
11. C.Thomas and J.Philippe, "Optimized Link State Routing Protocol (OLSR)," Published Online: RFC3626, http://rfc.net/rfc3626.txt, pp. 1–75, Oct 2003.
12. I. 802.11b, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band. IEEE, 1999.
13. I. 802.11a, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-speed Physical Layer in 5 GHz Band. IEEE, 1999.

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