Chapter 5

Multipath signal detection in a wireless Ad-hoc network

Chapter 4 presented the effects of multipath signal, Basic CDMA signal transmission and reception concepts, proposed improved multipath detection method, Experimental setup for performance evaluation of signal detection in five paths over AWGN and Rayleigh channel, statistically ordered algorithm. This technique is applied in a wireless ad-hoc network for multipath signal detection.

This chapter, deals with adhoc network, its implementation using Simulink Mathlab, 2009b and network simulator. Path establishment using shortest path algorithm, Selection of source and destination nodes, passing a data over it, analysis of data in intermediate nodes, reconstruction of lossy data using interpolation algorithm and results have been explained.

5.1 Wireless Networks

Wireless networks can be broadly classified into two categories: infrastructure-based and infrastructures-less as shown in Figure 5.1 Infrastructure-based networks include traditional cellular networks and wireless LANs (with centralized control module). Infrastructures less networks include ad hoc networks and sensor networks. Depending on the mobility of nodes, ad hoc networks can be further classified into mobile ad hoc networks (MANET) and static ad hoc networks. Multipath signal detection algorithm is developed and verified and has been applied for a wireless ad hoc network[96].

Figure 5.1: Wireless Networks: Taxonomy
5.1.1 Wireless Ad Hoc Networks

An ad hoc network is a collection of communication devices (nodes) that form a peer-to-peer network (no centralized server) temporarily in an ad hoc manner without any backbone infrastructure or base stations to meet some immediate needs. In ad hoc networks, individual nodes are responsible for dynamically discovering themselves and selecting suitable communication neighbors to form a connected multi-hop network topology. A key assumption in ad hoc networks is that not all nodes can directly communicate with each other, so nodes are required to relay packets on behalf of other nodes in order to deliver data across the network [97-98]. Each node in an ad hoc network can operate as a client or server as well as a router. In a mobile ad hoc network, the network topology, connectivity, and node locations are variable and can be changed dynamically.

Ad hoc networks are one of the most vibrant and active research fields today. Significant research in this area has been ongoing for nearly 30 years. The history of ad hoc networks can be traced back to 1972 and the Department of Defense (DoD) sponsored Packet Radio Networks (PRNET), which evolved into the Survivable Adaptive Radio Networks (SURAN) program in the earlier 1980s [99]. The goal of these programs was to provide packet switched networking to mobile battlefield elements in an infrastructure-less, hostile environment (soldiers, tanks, aircrafts, etc., forming the nodes in the network) [100]. The development languished during the 1980s simply because the hardware technology needed to achieve it, such as low cost CPU and memory for ad hoc routing, did not exist at that time. The interest in ad hoc networking was rekindled during the mid 1990s because of the advances of technologies, proliferation of laptop computers, and widespread use of wireless devices. The enabling technologies of ad hoc networks include the emergence of self-organizing systems, soft-ware defined radios (SDR), miniaturization of wireless devices, smart antenna, and battery technologies. The release of new frequency bands also provides the possibility of design and implementation of high speed data communication systems. Ad hoc networks are suitable for use in situations where infrastructure is either not available, not trusted, or should not be relied on in times of emergency [101]. Some application examples include: military soldiers in the battlefield communications; sensors scattered throughout an area for biological detection, environmental monitoring, or target tracking; an infrastructure-less network of notebook computers in a conference or campus setting; space explorations; undersea operations; etc. Although ad hoc networking research has a long history, significant challenges still exist. These challenges are summarized as follows [102].
Scalability: Scalability in ad hoc networks can be briefly defined as whether the ad hoc network can provide acceptable level of services (such as packet latency and network throughput) even when the number of nodes is large in the network.

Energy Efficiency: Since ad hoc networks assume no fixed infrastructure, individual nodes have to rely on limited battery power. Energy efficiency therefore becomes an important issue in ad hoc networks.

Quality-of-Service (QoS): QoS is an active research area even in wired packet switching networks. Ad hoc networks further complicated the QoS challenges because of the error-prone and time-varying characteristics of wireless channels. Furthermore, individual nodes in ad hoc networks must share the media with many neighbors, each with its own set of QoS requirements.

Security: Security is another open issue for ad hoc networks since nodes normally use shared wireless media in a potential insecure environment. Nodes are susceptible to denial of service (DoS) attacks that are harder to track down than in wired networks. Lack of Well Defined System Models: Finally, lack of well defined and widely accepted models for RF path attenuation, mobility, and traffic is another big issue. These tightly integrated models are required for a fair comparison and quantifying the system performance on a common baseline. Although the mechanisms behind electromagnetic wave propagation are moderately well understood, it is difficult to quantify in detail in an environment including large number of complex objects (such as foliage, cars, and buildings).

Among the various aspects of mobile ad hoc networks, medium access control and routing are two most active research areas. The multihop topology allows spatial reuse of the wireless spectrum. Two nodes can transmit using the same bandwidth, provided they are sufficiently apart. Many MAC protocols, including commercial standards like IEEE 802.11 [103-104] and HIPERLAN [105-107], are purely based on contention. These protocols are attractive because they are very simple and easy to implement. They work well under light traffic but suffer from collisions when the traffic becomes heavy.

5.2 The Routing Concept

Routing is defined as the process of finding a path from a source to some arbitrary destination on the network. This process operates in the Internet layer so packets can be forwarded across networks with different transmission mediums. The Internet is a collection of numerous networks and sub networks, which are interconnected by computers.
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which perform routing. Computers which perform routing are known as routers, and a router which routes between a subnet and an external network is known as a gateway. Traditional routing assumes that all computers on the network are static or semi-static. Therefore the router only needs to react to changes caused by failure of network links or other routers. So routers conventionally exchange routing information with other routers by periodically sending out routing specific control messages. Due to the fact that the topology of a fixed network is semi-static, the amount of control messages can be kept to a minimum[108].

Many assumptions for fixed networks are not valid for mobile networks as there are fundamental differences in how they operate. These differences are discussed in the next section.

5.2.1. Mobile Ad Hoc Network (MANET) Characteristics

A mobile ad hoc network (MANET) is an autonomous system of mobile routers (and associated hosts) connected by wireless links—the union of which form an arbitrary graph. The routers are free to move randomly and organize themselves arbitrarily; thus, the network’s wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet.” [109]. The fundamental difference between fixed networks and MANET is that the computers in a MANET are mobile. Due to the mobility of these nodes, there are some characteristics that are only applicable to MANET. Some of the key characteristics are described below [110].

1. Dynamic Network Topologies: Nodes are free to move arbitrarily, meaning that the network topology, which is typically multi-hop, may change randomly and rapidly at unpredictable times.

2. Bandwidth constrained links: Wireless links have significantly lower capacity than their hardwired counterparts. They are also less reliable due to the nature of signal propagation.

3. Energy constrained operation: Devices in a mobile network may rely on batteries or other exhaustible means as their power source. For these nodes, the conservation and efficient use of energy may be the most important system design criteria.

The MANET characteristics described above imply different assumptions for routing algorithms as the routing protocol must be able to adapt to rapid changes in the network
topology. They also present different optimization parameters such as bandwidth overhead and energy usage. A considerable amount of research has been done in the area of MANET, and this is presented below[111].

### 5.3. Current MANET Research

Mobile ad hoc networks, or MANET, are fundamentally different to traditional wired networks as wired networks are assumed to be stationary and static. This imposes different design requirement and constraints on routing protocols for MANET. There are two categories of routing protocols: table-driven and on-demand routing. In table-driven routing protocols, routing information is periodically advertised to all nodes so all nodes have an up to date view of the network. Alternatively, on-demand routing Protocols only discovers a new route when it is required. Hybrid routing protocols also exist and they try to achieve an efficient balance between both categories of protocols [112]. Table 5.1 shows a comparison between the two methodologies.

<table>
<thead>
<tr>
<th>Availability of Routing Information</th>
<th>Table-driven</th>
<th>On-demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Immediately from route Table</td>
<td>After a route discovery</td>
</tr>
<tr>
<td>Route Updates</td>
<td>Periodic Advertisements</td>
<td>When requested</td>
</tr>
<tr>
<td>Routing Overhead</td>
<td>Proportional to the size of the network regardless of network traffic</td>
<td>Proportional to the number of communicating nodes and increases with increased node mobility</td>
</tr>
</tbody>
</table>

It is clear that on-demand protocols are more suited for mobile handheld devices as network bandwidth and battery power is limited. This saving in network bandwidth and energy consumption is a tradeoff for up to date routing information. Generally speaking, on-'

### 5.4 Wireless Standards

Standards for wireless communications exist for different applications: cellular telephony, satellite communications, broadcast radio, local area networks, and so forth. Three well-known standards for wireless data communication have been proposed for use in WSNs, each with certain advantages. However, WSNs do not have widely accepted standard communication protocols in any of the layers in the OSI model sense. The
protocols provide wireless data transmission with appropriate data rates for a wide range of applications, they can be implemented in battery-powered devices, and they do not require complicated planning and setup. Several commercial products use these wireless standards, which could be an advantage for WSNs in cost and ease of implementation [113].

5.4.1 IEEE802.11

IEEE802.11 is a family of standards for wireless data communications with definitions for characteristics in the Physical and MAC layers. IEEE802.11b, for example, uses direct sequence spread spectrum (DSSS) with varying modulation schemes to maximize the data rate in a given noise environment. Differential binary phase shift keying (DBPSK) is used for 1 Mbps, differential Quadrature phase shift keying (DQPSK) for 2 Mbps, and complementary code keying (CCK) for 5.5 and 11 Mbps.

The MAC protocol has two modes (i) DCF (Distributed Coordination Function) Mode with no central device controlling the communication. DCF uses CSMA/CA in any of the following ways. Carrier sensing: a node senses the medium. If it is idle, the node transmits the data frame. If the medium is busy, the node waits until it becomes idle again, waits for a random time and transmits. Upon frame reception, the receiver node answers with an ACK (acknowledgment) control frame. If a collision occurs, transmitting nodes wait a random time and try again later. Virtual carrier sensing: a node with a frame to transmit senses the medium. If it is idle, the node sends a control frame called RTS (request to send), which contains the intended receiver address and the time required to send the information (transmission delay). If the destination node agrees to communicate, it will answer with a CTS (clear to send) control frame which also contains the delay. All nodes hearing RTS or CTS should refrain from transmission until the transmission delay has elapsed and the medium is idle again. The receiver must respond with an ACK for each data frame received [114].

(ii) PCF (Point Coordination Function) A special node, the access point (AP), polls every node and controls the communication process. An AP periodically broadcasts a beacon control frame with parameters and invitations to join the network [9]. Advantages of IEEE802.11 include that it is widely used, so it is easy to find networks supporting the standard. Data rates are high for wireless end user transmission and radio ranges can be hundreds of meters. Also, as IEEE802.11 supports well-known protocols as
TCP and IP, devices connected with this technology may have easy access to the Internet and this way they can send information anywhere in the world[115].

Disadvantages include the large overhead in control and data packets. 802.11 requires 34 bytes for the header and the checksum, TCP and IP require a minimum of 20 bytes for each header, so there is at least 74 bytes of overhead to send application information, which in WSNs may be only two bytes. Another possibility is using UDP which employs less overhead, 8 bytes for the header. However, UDP uses IP and 802.11 MAC headers add 62 bytes total to the application information. Perhaps the most important problem for using 802.11 in WSNs is energy consumption. Even though the standard has power saving mechanisms, according to Ferrari et al. “power consumption is rather high, and the short autonomy of a battery supply still remains the main disadvantage of the proposed IEEE802.11 sensor system.

IEEE802.15.1, Bluetooth the IEEE also defined MAC and physical layer characteristics for the 802.15.1 standard. In this standard, the physical layer uses 2.4 GHz, frequency hopping spread spectrum (FHSS) with Gaussian frequency shift keying (GFSK) as the modulation scheme. IEEE802.15 defines wireless personal area networks (WPANs) allowing connectivity in a 10-meter range. However, some Bluetooth devices have 100-meter range.

An 802.15.1 master node controls up to 7 active slaves and up to 255 non active slave nodes. These networks are referred to as picoNet and several picoNet may communicate using a bridge node, forming a Scatternet. The MAC protocol uses polling with a time division multiplexing (TDM) scheme called time division duplex. In one time slot, the master will poll a single slave, inquiring if it has something to send. If the slave has data to transmit, it sends it to the master in the next time slot. A master node must periodically transmit, even if there is no data to be exchanged, to keep slaves synchronized. Slaves cannot communicate directly; the information must go through the master node. [117].

IEEE802.15.4

The IEEE defined physical and MAC layer characteristics for establishing connectivity between devices with low-power consumption, low cost, and low data rate. The standard is related to ZigBee technology since The ZigBee Alliance (association of several companies such as Samsung and Motorola) defines the other communication layers (above MAC) for 802.15.4 compliant devices. Frequency bands are 2.4 GHz and 868/915 MHz, both
working with DSSS. The 2.4 GHz band has a 250 kbps data rate using offset Quadrature phase shift keying (O-QPSK) modulation. The 868/915 MHz band has data rates up to 240 kbps using BPSK. Typical radio range according to the standard is 10 meters. Maximum packet size is 128 bytes with payload of 104 bytes. 64-bit IEEE or 16-bit addresses can be used. The 802.15.4 standard defines two types of devices.

Table 5.2: WSNs MAC Protocol Comparison.

<table>
<thead>
<tr>
<th>Name</th>
<th>Implemented</th>
<th>Applications</th>
<th>Synch. requirement</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-MAC</td>
<td>Hardware</td>
<td>Event-driven, long idle periods, delay order of message time</td>
<td>Loose</td>
<td>RTS, CTS, ACK, SYNC</td>
</tr>
<tr>
<td>B-MAC</td>
<td>Simulation/hardware</td>
<td>Delay tolerant Low delay, long idle periods</td>
<td>None</td>
<td>Preamble</td>
</tr>
<tr>
<td>PW-MAC</td>
<td>Hardware</td>
<td>High data rates, large energy source, smart terminals</td>
<td>None</td>
<td>Beacon</td>
</tr>
<tr>
<td>IEEE 802.11</td>
<td>Simulation/hardware</td>
<td>Medium to low data rates, low-energy consumption</td>
<td>None</td>
<td>RTS, CTS, ACK</td>
</tr>
<tr>
<td>IEEE 802.15.1</td>
<td>Simulation/hardware</td>
<td>Medium to low data rates, low-energy consumption</td>
<td>Tight</td>
<td>Synch transmissions, S, C</td>
</tr>
<tr>
<td>IEEE 802.15.4</td>
<td>Simulation/hardware</td>
<td>Medium to low data rates, low-energy consumption</td>
<td>Tight</td>
<td>Beacon, ACK</td>
</tr>
</tbody>
</table>

Figure 5.2.: Plantronics M1000 Bluetooth headset

5.5. Commercial Products

There are a number of wireless products available, but only a few technologies have ad hoc capabilities. Products based on these technologies will be discussed below.
5.5.1. Bluetooth

Bluetooth is a technology that promises fast, secure, point-to-point wireless communications over short distances (approximately 10 meters) for devices as diverse as mobile phones, consumer electronics appliances and desktop computers. It uses spectrum in the unlicensed ISM3 band of 2.4 to 2.48GHz. Besides being a hardware standard, Bluetooth defines a protocol stack that allows for hierarchical ad hoc networking in the form of “piconets”, in which Bluetooth devices form themselves into point-to-multipoint picocells of seven slaves under the control of one master. Multiple piconets in overlapping coverage areas form scatternets.

Although Bluetooth has been standardized for quite some time, the devices are just beginning to become available. The Bluetooth devices which are currently available are only single hop devices as the formation of scatternets is not specified in the current version of the Bluetooth standard. Figure 5.2 shows a wireless headset based on Bluetooth technology from Plantronics.

5.5.2. IEEE 802.11b

IEEE 802.11b is wireless local area network communications standards that operate in the 2.4GHz band at data rates of 1 to 11Mbps and distances of 25 to 550 meters [9]. In an IEEE 802.11 network, there are two possible modes: ad hoc mode, where all nodes in the network must be within range of each other, and the infrastructure mode, in which all inter-node communication must pass via access points.

The ad hoc mode allows nodes to form an ad hoc network, but the communication is limited to single hop, with no multi-hop capabilities. Since the IEEE 802.11 standard only defines the host-to-network layer, it is up to upper layer protocols to incorporate multi-hop capabilities. Unlike Bluetooth, IEEE 802.11b products are widely available and are currently used by many corporations and institutions.

5.5.3. Current Products Comparison

From the product comparison shown in Figure 5.2, it can be seen that current ad hoc networking solutions are limited to single hop operation. The network range can be slightly extended with the use of access points but that requires preexisting networking infrastructure to be present.
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picoNet provides a solution to this problem by adding multi-hop routing capabilities to existing ad hoc networks. This will allow a multi-hop network to be deployed with no preexisting networking infrastructure. It will also allow a multi-hop ad hoc network to form as an extension to an existing network.

Table 5.3. Features of commercial ad hoc products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IEEE 802.11b</th>
<th>Bluetooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Rate</td>
<td>1 - 11 Mbps</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Range</td>
<td>25 - 550 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Adhoc Capabilities?</td>
<td>Only single hop, not multi Hop</td>
<td>Only single hop (Multi hop not specified)</td>
</tr>
<tr>
<td>Cost</td>
<td>~AUD$300</td>
<td>~AUD$300</td>
</tr>
</tbody>
</table>

5.6 Shortest path algorithm to establish path in Ad hoc Network (Routing algorithm.)

Unlike traditional wireless networks, characterized by the presence of last-mile, static and reliable infrastructures, Mobile ad hoc Networks (MANETs) are dynamically formed by collections of mobile and static terminals that exchange data by enabling each other's communication. Supporting multi-hop communication in a MANET is a challenging research area because it requires cooperation between different protocol layers (MAC, routing, transport). Many routing solutions specifically designed for Wireless Ad hoc networks (WLAN) have been proposed. In these proposals, the unique properties of the WLANs have been taken into account. Routing techniques can be classified according to the protocol operation into negotiation based, query based, QoS based, and multi-path based. The negotiation based Protocols have the objective to eliminate the redundant data by include high level data descriptors in the message exchange. In query based protocols, the sink node initiates the communication by broadcasting a query for data over the network. The QoS based protocols allow sensor nodes to make a tradeoff between the energy consumption and some QoS metrics before delivering the data to the sink node]. Finally, multi-path routing protocols use multiple paths rather than a single path in order to improve the network performance in terms of reliability and robustness. Multi-path routing establishes multiple paths between the source-destination pair. Multi-path routing protocols have been discussed in this chapter. Mutli-path routing has focused on the use of
multiple paths primarily for load balancing, fault tolerance, bandwidth aggregation, and reduced delay. We focus on supporting quality of service through multi-path routing. In this work, we propose an Energy Efficient and QoS aware multipath routing protocol (abbreviated shortly as EQSR) that maximizes the network lifetime through balancing energy consumption across multiple nodes, uses the concept of service differentiation to allow delay sensitive traffic to reach the sink node within an acceptable delay, reduces the end to end delay through spreading out the traffic across multiple paths, and increases the through put through introducing data redundancy. EQSR uses the residual energy, node available buffer size, and Signal-to-Noise Ratio (SNR) to predict the best next hop through the paths construction phase. Based on the concept of service differentiation, EQSR protocol employs a queuing model to handle both real-time and non-real-time traffic.

Figure 5.3 Path discovery

This protocols use multiple paths rather than a single path in order to improve the network performance in terms of reliability and robustness. Multi-path routing has focused on the use of multiple paths primarily for load balancing, fault tolerance, bandwidth aggregation, and reduced delay. We focus on supporting quality of service through multi-path routing.

Assumption:

By considering N identical sensor nodes are distributed randomly in the sensing filed. All nodes have the same transmission range, and have enough battery power to carry their sensing, computing, and communication activities. The network is fully connected and dense. Each node in the network is assigned a unique ID and all nodes are willing to participate in communication process by forwarding data. Furthermore, we assume that the sensor nodes are stationery for their lifetime. Additionally, at any time, we assume that each sensor node is able to compute it residual energy, and its available buffer size, bandwidth as well as record the link performance between itself and its neighboring node.
in terms of signal-to-noise ratio (SNR). By examining recent link performance data, predications and decisions about path stability may be made.

**Link cost function**

The link cost function is used by the node to select the next hop during the path discovery phase. Let $N_x$ be the set of neighbors of node $x$. Then our cost function includes an energy factor, available buffer factor, bandwidth factor and interference factor with appropriate weights ($\alpha$, $\beta$, and $\gamma$):

$$\text{Next hop} = \max_{y \in N_x} \{ \alpha E_{\text{resd}, y} + \beta B_{\text{buffer}, y} + \gamma I_{\text{interference}, xy} \},$$

where, $E_{\text{resd}}, y$ is the current residual energy of node $y$, where $y N_x$, $B_{\text{buffer}, y}$ is the available buffer size of node $y$, and $I_{\text{interference}, xy}$ is the SNR for the link between $x$ and $y$.

The total cost ($C_{\text{total}}$) for a path $P$ consists of a set of $K$ nodes is the sum of the individual link costs $l(xy)i$, $i \in K$ along the path. Then we have:

$$C_{\text{total}, P} = \sum_{i=1}^{K-1} l(xy)i$$  \hspace{1cm} (5.1)

**Paths Discovery Phase**

Based on the idea of the directed diffusion the sink node starts the multiple paths discovery phase to create a set of neighbors that able to forward data towards the sink from the source node. The constructed multi-paths are node-disjoint paths (i.e. have no common nodes except the source and the destination).

The path discovery procedure is executed according to the following phases:

**I Initialization phase:** Each sensor node broadcast a HELLO message through the network in order to have enough information about which of its neighbors can provide it with the highest quality data. Each sensor node maintains and updates its neighboring table during this phase. The neighboring table contains information about the list of neighboring nodes of the sensor node. Figure 5.4 illustrates the structure of the hello message. The link quality field is expressed in terms of signal-to-noise ratio (SNR) for the link between the any node and its neighbor. Hop count gives the distance in hops for the message from its originator.
II Primary Path discovery phase:
After initialization phase each sensor node has enough information to compute the cost function for its neighboring nodes. Then, the sink node locally computes its preferred next hop node using the link cost function, and sends out a RREQ message to its most preferred next hop. Similarly, through the link cost function, the preferred next hop node of the source computes locally its most preferred next hop in the direction of the source node, and sends out a RREQ message to its next hop, the operation continues until sink node (see figure 5.3).

III Alternative Paths discovery phase: For the second alternate path, the source sends alternate path RREQ message to its next most preferred neighbor. To avoid having paths with shared node, we limit each node to accept only one RREQ message. For those nodes that receive more than one RREQ message, only accept the first RREQ message and reject the remaining messages. In figure 5.3, Node with double arrow computes its next preferred neighbor finds it Node 7. Node 9 generates RREQ message and forwards to node 7, but node 7 has been included in the primary path, then node 7 simply responds to node 9 with an INUSE message indicating that node 7 is already selected in a routing path. Immediately node 9, searches its neighboring table and computes the next preferred neighbor, which will be node 5, and sends out RREQ message to it. Node 5 accepts the message and continues the procedure in the direction of the sink node).

Paths Selection: After the completion of paths discovery phase and the paths have been constructed, we need to select a set of paths from the N available paths to transfer the traffic from the source to the destination with a desired bound of data delivery. Following the work done in the number of required paths is calculated.

5.6.1 Algorithms

Phase 1 (Path selection)
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1: Select the source node
2: Measure energy, free buffer, interference of each forwarded neighbor node
3: Measure the next hop using cost function.

Next hop = \( \max_{y \in N_x} \{ \alpha E_{\text{resd}_y}, y + \beta B_{\text{buffer}_y}, y + \gamma I_{\text{interference}, xy} \} \)

4: Find the maximum quality factor to select next neighbor.
5: Repeat step 2 to 4 till destination is reached.

Phase 2 (Quality of Service)

6: Read energy, free buffer, bandwidth, interference of each node in the path.
7: Measure the link established between every node using total cost function.

\[
C_{\text{total, } P} = \sum_{i=1}^{k-1} c_{(x,y)}^i
\]

(5.2)

8: Find the quality factor greater than desired value
\( Q_f > \) or \( < T_d \)
9: If node parameter is greater than desired value, divert the packet to its next neighbor and repeat step 2 to 4.
10: end.

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Figure 5.6 Flow chart for Data Flow through Network
5.7. Multipath detection in Ad hoc Network

The dynamic Ad hoc network for 50-100 nodes was created and the shortest path between source nodes to destination node was calculated. Using the least BER signal which was calculated from five users was selected to send the video signal via Adhoc network over the shortest path calculated dynamically. During this process when the nodes in the shortest path were error free the received signal was almost same as the transmitted signal.

The same signal was sent over shortest path by inserting block hole (nodes which blocks the data) in between source node and destination node, the signal takes the alternate path whenever it finds the block hole on the path. The alternate path was selected based on the strength of the nodes on the alternate paths.

The simulation results are shown below:

Figure 5.7 Ad hoc network for 50 nodes

Figure 5.8: Ad hoc network for 50 nodes with shortest path between source and destination node
5.8. Data transmission and reconstruction

A mobile ad hoc network (MANET) is a self-configurable, self-organizing, infrastructure less multi-hop mobile wireless network each node in a MANET is capable of moving independently, thus the network topology can change continuously and dramatically. Each node also functions as a router that discovers and maintains routes to other nodes and forwards packets for other nodes. A MANET can be promptly deployed without any wired base stations or infrastructure support. Few administrative actions need to be performed to set up such a network. The rapidly deployable and self-organizing features make a MANET very attractive in tactical and military applications and security is a critical issue in a mobile ad hoc network.

5.9 Image Interpolation Concept

Image interpolation techniques are referred in literature by many terminologies, such as image resizing, image sampling, digital zooming, image magnification or enhancement, etc. Basically, an image interpolation algorithm is used to convert an image from one resolution (dimension) to another resolution without losing the visual content in the picture. Image interpolation algorithms can be grouped in two categories, non-adaptive and adaptive. The computational logic of an adaptive image interpolation technique is mostly dependent upon the intrinsic image features and contents of the input image whereas computational logic of a non-adaptive image interpolation technique is fixed irrespective of the input image features.

When the image is interpolated from a higher resolution to a lower resolution, it is traditionally called image down-scaling or down-sampling. On the other hand, when the image is interpolated from a lower resolution to a higher resolution, it is referred as image up-scaling or up-sampling. Most of the image interpolation techniques in the literature have been developed by interpolating the pixels based on characteristics of local features such as edge information, nearest neighbor criteria, etc. Non-Adaptive Algorithms for Image Interpolation is considered and certain computations are performed indiscriminately to the whole image for interpolation regardless of its contents. There are different types of interpolation algorithms which are used for image interpolation and they are (i) Neighbor Replacement (ii) Bilinear Interpolation (iii) Bicubic Interpolation. Among these three algorithms, Bicubic Interpolation algorithm is used in our work, ie for video signal to improvise the lossy signal.
Nearest Neighbor Replacement: The simplest interpolation method is just to replace the interpolated point with the nearest neighboring pixel. The only advantage of this approach is the simplicity and low computation. However, the resultant pixelization or blocky effect makes the image quality unacceptable for most high quality imaging applications.

Bilinear Interpolation: The bilinear interpolation can be considered as a weighted average of four neighboring pixel values.

Bicubic Interpolation: The bicubic interpolation uses sixteen \((4×4)\) neighboring pixels for estimation. It approximates the local intensity values using a bicubic polynomial surface. The general form for a bicubic interpolation is as follows:

\[
I_{xy} = \frac{3}{2} \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j = a_{00} + a_{01} x + a_{02} y + a_{03} x^2 + a_{04} x y + a_{05} y^2 + a_{12} x^2 y + a_{13} x y^2 + a_{23} x y^2 + a_{33} y^3
\]

In order to do a bicubic interpolation within a grid square, one need to calculate the gradients (the first derivatives) in both the \(x\) and \(y\) directions and the cross derivative at each of the four corners of the square.

5.9.1 Discrete Wavelet Transform for Image Interpolation.

Adaptive interpolation is proposed based on logics of local structure of the image and intensity variations that are indistinguishable by human eyes. In this section, we propose a novel image interpolation algorithm using the Discrete Wavelet Transform (DWT). The proposed method preserves much of the sharp edge features in the image, and lessens the amount of color artifacts. Effectiveness of the proposed algorithm has been demonstrated based on evaluation of PSNR and \(\Delta E_{ab}\) quality metrics with a large database of different types of images. The proposed technique is simple to apply in terms of both software and hardware implementations. First we briefly introduce the concept of DWT in the context of the theme of the current work and then explain the proposed method for image interpolation [118].

5.9.2. Discrete Wavelet Transform

DWT can be implemented by filtering operations with well-defined filter coefficients [5, 6]. In traditional convolution based approach to compute forward DWT, the input signal \(x\) is filtered separately by a low-pass filter \(\tilde{h}\) and a high pass filter \(\tilde{g}\). The two output streams are then sub-sampled by simply dropping the alternate output samples in
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Each stream to produce the low-pass ($y_L$) and high-pass ($y_H$) sub band outputs as shown in Fig. 5.9. The two filters ($\tilde{h}$) form the analysis filter bank. The original signal can be reconstructed by a synthesis filter bank ($h, g$) starting from $y_L$ and $y_H$ as shown in Fig. 5.9. Given a discrete signal $x(n)$, the output signals $y_L(n)$ and $y_H(n)$ in Fig. 5.9 can be computed as

\begin{align}
  y_L(n) &= \sum_{i=0}^{T_L-1} \tilde{h}(i) \times x(2n - i), \tag{5.4} \\
  y_H(n) &= \sum_{i=0}^{T_H-1} \tilde{g}(i) \times x(2n - i) \tag{5.5}
\end{align}

where $\tau_L$ and $\tau_H$ are the lengths of the low-pass ($\tilde{h}$) and high-pass ($\tilde{g}$) filters respectively. For inverse transform, both $y_L$ and $y_H$ are first up-sampled by inserting zeros in between two samples and then filtered by low-pass ($h$) and high-pass ($g$) filters respectively. Then they are added to obtain the signal ($x'$) as shown in Fig. 5.9

![Figure 5.9 Analysis and Synthesis filtering in DWT](image)

For multi-resolution wavelet decomposition, the low-pass sub band ($y_L$) is further decomposed in a similar fashion in order to get the second-level of decomposition, and the process is repeated. The inverse process follows similar multi-level synthesis filtering to reconstruct the signal. Image signals are two dimensional signals. Since most of the practical two dimensional wavelet filters are separable functions, the 2-D DWT can be implemented by applying the 1-D DWT row-wise to produce an intermediate result (L and H sub bands in each row) and then applying the same 1-D DWT column-wise on the intermediate result, as shown in Fig. 5.9 (a).

In the first level of decomposition, four sub bands LL1, LH1, HL1 and HH1 are obtained. Applying the same process in LL1 sub band, it produces LL2, LH2, HL2 and HH2 in the second level and so on, as shown in Fig. 5.9 (b)-(c).
5.9.3 Image Interpolation by DWT

The input image \( I \) with each pixel multiplied by a scaling factor \( s \). This scale factor \( s \) is set equal to the square of the DC gain of the selected analysis low-pass filter. Depending upon the implementation of the discrete wavelet transform, one may choose a different DC gain for the analysis low-pass filter and Nyquist gain for the analysis high-pass filter, or even choose different filters. For a given \( n \)-taps analysis low-pass filter, \( \tilde{h}(n) \)

the expression \( \left| \sum_n \tilde{h}(n) \right| \) denotes the DC gain; while denotes the \( \left| \sum_n (-1)^n \tilde{g}(n) \right| \) Nyquist gain of a \( n \)-tap high-pass analysis filter. \( \tilde{g}(n) \).

Hence the dimension of the new LL sub band is the same as the resolution \( m \times n \) of the original image \( I \). The HH sub band of the virtual DWT image (I ‘DWT’) is set all zeros with dimension \( m \times n \). The new HL and LH sub bands of the virtual DWT image are generated from the original HL and LH sub bands (computed in the first step) by inserting zeros in alternate rows and columns as shown in Fig. 5.11(b).
5.9 Flow charts

Figure 5.11: DWT on image data

Figure 5.12  Flow chart for image interpolation
The adaptive are usually computationally expensive compared to the non-adaptive techniques. The DWT based image interpolation algorithm proposed in this paper is adaptive in nature by virtue of the characteristics of DWT which divides the image into low and high frequency sub bands. The directional edge information (vertical, horizontal, and diagonal) in the image are embedded into the high frequency DWT sub bands.

5.10. Analysis of signal

Impulse Response, Space Invariance, Discrete Convolution, Computing, Convolution, Image Filtering. Many image processing (filtering) operations are modeled as a linear system

\[
\delta(x, y) \rightarrow \text{Linear Systems} \rightarrow h(x, y)
\]

\[
g(x, y) = f(x, y) * h(x, y) = \sum_{-\infty}^{\infty} \iint f(x', y') h(x - x', y - y') dx dy
\]

System’s output to an impulse \( \delta(x,y) \)

![Figure 5.13 Impulse Response](image)

g(x,y) remains the same irrespective of the position of the input pulse
The filtered image is described by a discrete convolution. The filter is described by a \( n \times m \) discrete convolution mask

\[
g(i,j) = f(i,j) \ast h(i,j) = \\
\sum_{k=1}^{n} \sum_{l=1}^{m} f(k,l) h(i-k, j-l)
\]

5.7

Figure: 5.14 Image Mapping technique (a)

Invert the mask \( g(i,j) \) by \( 180^\circ \), not necessary for symmetric masks. Put the mask over each pixel of \( f(i,j) \). For each \( (i,j) \) on image

\[
h(i,j) = A_p1 + B_p2 + C_p3 + D_p4 + E_p5 + F_p6 + G_p7 + H_p8 + I_p9
\]

(5.8)
Images are often corrupted by random variations in intensity, illumination, or have poor contrast and can’t be used directly so Filtering, image characteristics Enhancement, Template matching are to be done. Hence filtering is used to transform the pixel intensity values to reveal certain image characteristics, Enhancement is used to improve the contrast, Smoothing remove the noise and Template matching detects known patterns, Match template with image at every pixel distance matches the image at the current location.

\[
D^2(x, y) = \sum_{x=0}^{m} \sum_{y=0}^{n} [(f(x', y') - t(x' - x, y' - y)]^2
\]

Equation (5.9)

\[
\sum_{x=1}^{M} \sum_{y=1}^{N} [f(x', y') - t(x' - x, y' - y)]^2 =
\]

\[
\sum_{x=1}^{M} \sum_{y=1}^{N} f(x', y')^2 + 
\]

\[
\sum_{x=1}^{M} \sum_{y=1}^{N} t(x' - x, y' - y)^2 - 
\]

\[
2 \sum_{x=1}^{M} \sum_{y=1}^{N} f(x', y') t(x' - x, y' - y)
\]

Equation (5.10)
Figure 5.16: Flow chart for Video Reconstruction main flow
Figure 5.17: Flowchart Video Reconstruction sub flow
Figure 5.18: flow chart for Image reconstruction (mapping)
Figure 5.19: The average rate of the energy (simple routing) 1

Figure 5.20: The average path length (simple routing) 2

Figure 5.21 The average path length (proximity Base Station)
Figure 5.22: Transmitted Video signal.

Figure 5.23: Network created for data to be sent

Figure 5.24: Input signal with highest receiving power

Figure 5.25: Transmission of Data
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Figure 5.26: Reconstructed video signal (lossy)

![Reconstructed video signal (lossy)](image1)

Figure 5.27: Reconstructed video signal using Reconstruction Algorithm.

![Reconstructed video signal using Reconstruction Algorithm.](image2)

Input file Name: AkiyoQCIF
Input file Name Resolution: Width: 176 Height: 144
Frame Size: 25 (KBytes)

----------------------
BER of 1 System is: 0.146474
BER of 2 System is: 0.311107
BER of 3 System is: 0.162494
BER of 4 System is: 0.093046
BER of 5 System is: 0.070520
5 Receiver's Power is More

Network Parameters:

Channel Type : WirelessChannel
Radio Propagation Model : TwoRayGround
Network Interface Type : WirelessPhy
MAC Type : 802_11
Interface Queue Type : PriQueue
Link Layer Type : LL
Antenna Model Type : OmniAntenna
Max Packet in IFQ : 100
Packet Size(bytes) : 1024
SubPacket Size(bytes) : 256
Routing Protocol : AODV
Scenario X Dimension (meters) : 1000.0
Scenario Y Dimension (meters) : 1000.0
Initial Energy (joules) : 10
Reception Energy (watts) : 0.07
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Transmission Energy (watts) : 0.02
Sleep Mode Power (watts) : 0.000015
Total Number of Nodes : 25

Network is created with 25 nodes
Nodes are uniformaly distributed

Node Configuration :
Nodes are configured with Energy 10 Joules
Nodes are configured with Free Buffer Size 1000 packets
Nodes are configured with Hop Counts 0
Nodes are configured with Delay 25 ms
Nodes are configured with SNR Inf
Nodes are configured with Transmission Range 50 meter
Nodes are configured with Transmission Capacity 200 Kbps

Packet Configuration :
Packets are configured with SourceID -1
Packets are configured with DestinationID -1
Packets are configured with PacketID 0
Packets are configured with PacketData 1024 (Bytes)
Packets are configured with NextNode -1
Packets are configured with Hop Counts 0
Packets are configured with Residual Energy 0
Packets are configured with Free Buffer 0
Packets are configured with Link Quality 0
Packets are configured with SNR Inf

Radio Propagation Model : TwoRayGround
Interface Queue Type : PriQueue
Antenna Model Type : OmniAntenna
Max Packet in IFQ : 100
Scenario X Dimension (meters) : 1000.0
Scenario Y Dimension (meters) : 1000.0

Table 5.4 Network parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network field</td>
<td>176m*144m</td>
</tr>
<tr>
<td>Number of Sensors</td>
<td>25-100</td>
</tr>
<tr>
<td>Number of sinks/Number of Sources</td>
<td>1/1</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>50m</td>
</tr>
<tr>
<td>Transmission Capacity</td>
<td>200 Kbps</td>
</tr>
<tr>
<td>MAC Layer</td>
<td>IEEE 802.11</td>
</tr>
<tr>
<td>Weights(α,β,γ)</td>
<td>3/2/3</td>
</tr>
<tr>
<td>Max Buffer size</td>
<td>256 K-byte</td>
</tr>
<tr>
<td>Buffer threshold</td>
<td>1024</td>
</tr>
<tr>
<td>Simulation time</td>
<td>1000 seconds</td>
</tr>
</tbody>
</table>
5.11 Conclusion

In this chapter, the research work carried out on CDMA Ad hoc network has been explained. The simulation of statistical multipath signal passing through five different channels is presented. The signal having the highest SNR is considered at the receiver and the BER for that particular signal is calculated and is explained in chapter 4. This could be used in wireless communication to identify the signal having the highest SNR.

Tested signal for highest receiving power in different environment is used in Ad hoc network to transmit the data (video signal) through path and using shortest path algorithm data is transmitted. In Ad hoc network, while transmitting the real time signal, the block hole was inserted to block the exact recovery of the signal at the receiver. The signal takes alternate path (with highest strength) to transmit the data whenever it finds the block hole on the path. The alternate path was selected based on the strength of the nodes on the alternate paths. Due to this block hole in the network there is a small amount of data loss and is visible in the form of patches in the reconstructed data, and this can be minimized using data reconstruction algorithm at the receiver. In the absence of block hole on the path, the transmitted data is same as receiving data with minimum negligible loss. Hence selecting the lowest BER signal and transmitting the data in the Ad hoc network is proved to be efficient way of communication CDMA.

<table>
<thead>
<tr>
<th>Channel Type</th>
<th>WirelessChannel</th>
</tr>
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<tbody>
<tr>
<td>Network Interface Type</td>
<td>WirelessPhy</td>
</tr>
<tr>
<td>MAC Type</td>
<td>802_11</td>
</tr>
<tr>
<td>Link Layer Type</td>
<td>LL</td>
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<tr>
<td>Packet Size(bytes)</td>
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</tr>
<tr>
<td>SubPacket Size(bytes)</td>
<td>256</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>A2ODV</td>
</tr>
<tr>
<td>Initial Energy (joules)</td>
<td>10</td>
</tr>
<tr>
<td>Reception Energy (watts)</td>
<td>0.07</td>
</tr>
<tr>
<td>Transmission Energy (watts)</td>
<td>0.02</td>
</tr>
<tr>
<td>Sleep Mode Power (watts)</td>
<td>0.000015</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>50 meter</td>
</tr>
<tr>
<td>Data packet size</td>
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<tr>
<td>802.11 data rate</td>
<td>2Mbp</td>
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<tr>
<td>CDMA data rate</td>
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<tr>
<td>Control channel rate</td>
<td>400Kbps</td>
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<tr>
<td>SNR threshold</td>
<td>10dB</td>
</tr>
<tr>
<td>Reception threshold</td>
<td>-94dBm</td>
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