Cross Layered Routing Implementation for Ultra Wideband Communication

ABSTRACT
The current routing implementations for wireless systems are based on the network architecture developed for wire-line networks. The physical characteristics of the wireless media are not used for network optimization. The emergence of Ultra wideband, a high frequency transmission technology providing high transmission rates, has implied we reconsider the current network architecture. A salient feature of ultra wideband is the ability to measure the physical distance between the transmitter receiver pair. We develop a cross layered architecture that utilizes physical layer parameters for reducing mobile node discontinuities in networks. The positional information is made available to the routing layer for generating an alternate path to the mobile node as a provision for future discontinuities. This improves the network connectivity for the mobile node and reduces its power consumption due to the nonexistence of route requests.

KEY WORDS
Ultra Wideband, ad hoc networks, cross layering, wireless communication, and mobile node routing

1. Introduction

The transformation of the OSI model to the TCP/IP model, combining the physical layer and the link layer signified the emergence of wired networks. These networks have lower data errors resulting in reduced number of retransmissions. TCP/IP protocol is suited to handle retransmissions so there wasn’t much required in terms of efficiency by the physical medium.

The introduction of wireless networks pose a different problem as the physical layer, a wireless channel varies dynamically due to the motion of devices or variation in environmental conditions. Error free data transfer rates are defined by the wireless channel characteristics. Wireless networks are designed assuming worst case conditions at each layer. However, these conditions concurrently exist for a small percentage of the transmission time, leading to over provisioning. Cross layered design allows the systems to examine channel conditions for optimizing overall system performance. The current channel conditions are utilized by the Internet Layer for optimum routing using metrics such as low noise or interference. We propose the utilization of physical layer parameters to reduce the effect of system mobility in an ad hoc network scenario. The application of our proposal would lead to an improved network performance with a reduced control overhead.

Related work
Geographic Adaptive protocol [5]: Energy-aware, location based routing algorithm, divides the complete area into zones to form a grid structure. The nodes use GPS capabilities to locate their position in the grid. Node mobility is handled by the mobile node which estimates its residing time in the grid. When the residual time expires another node within the grid takes over the responsibilities of the previous node.

Most Forward within Radius (MFR) [3]: Greedy routing algorithm, minimizes the number of hops using the distance from the destination. MFR causes local optimizations and does not account for node mobility. A variation to this routing scheme is the Compass Routing strategy which selects nodes on or closer to the straight line connecting the source and the destination.

SPAN [2]: Position based routing algorithm which selects nodes as coordinators based on positional information. The coordinators operate as the network backbone, forwarding messages. A node is promoted to the coordinator if there is no connection between its 2 neighboring nodes using the currently established coordinators.

These routing protocols utilize the strength of the received signal as a pointer to the distance between the transmitter and the receiver. A drawback of this system is the distance miscalculation triggered by the reduction in received signal strength due to interference, multi-path fading or environmental factors. The implementation of GPS capability for every node would increase the cost and power consumption of the system.

The absence of an actual physical layer in wireless networks makes connection reliability an important criterion. Ad hoc networks consist of battery operated nodes resulting in power and performance constraints for routing protocol design. Node mobility further complicates the prediction and selection of optimum transmission routes. The goal of our research is to reduce the complexity introduced by the motion of the nodes using the physical layer metrics and the performance features of UWB.

2. Proposed Implementation

We aim to predict the time instance when a mobile node would go beyond the coverage area of its currently connected fixed node. This would be helpful to generate a set of alternate routing paths to the mobile node in the event of a disconnection. The alternate route, requested in advance would ensure continuous connectivity to the
mobile node. The system gain would be the reduction in packets dropped due to a failed connection or erroneous packet routing and the energy conserved by the lack of the mobile node route requests. This intelligent routing of packets would reduce the processing load on the nodes and improve the wireless transmission rates. The prevalent dynamic source routing scheme is a reactive scheme [4]. A modification in the scheme is recommended to make it proactive to improve the network performance.

The prediction of the mobile node’s residual time requires continuous monitoring of the mobile node motion. This is achieved using Ultra wideband, which is a high frequency impulse signal immune to Rayleigh fading and environmental delays. UWB is tested to measure physical distances within a centimetre. [1]

We consider a stationary node to be placed at location (0, 0) and the mobile node located at (d, y1) at the time instance t = 0. The mobile node follows the trajectory of the vertical line to point (d, y2). The distance between the mobile node to the stationary node is denoted by r (t).

The equations for the x and y co-ordinates of the line can be expressed as

\[ x(t) = d \]
\[ y(t) = y_1 + v \times t \]

where \( v \) = velocity of the mobile node in time \( t \).

The distance of the mobile node from the stationary node can be expressed as

\[ r(t) = \sqrt{x^2(t) + y^2(t)} \] (1)
\[ r(t) = \sqrt{d^2 + y^2(t)} \]

\[ r(t) = y(t) \sqrt{1 + \frac{d^2}{y^2(t)}} \] (2)

In the optimum case the mobile node trajectory would pass through the stationary node or within close proximity of the stationary node. Thus the minimum distance “d” between the mobile node trajectory and the stationary node would be negligible compared to that in the y-direction as can be observed in the plot below.

Figure 1. Mobile Node Trajectory

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Figure 2. Inter-nodal distance

Hence, in that case

\[ \frac{d^2}{y^2(t)} < 1 \]

The Taylor Series for \( x < 1 \) can be expressed as

\[ \sqrt{1 + x} \approx 1 + \frac{x}{2} \]

Using Taylor’s series expansion, equation (2) can be reduced as below

\[ r(t) \approx y(t) \left[ 1 + \frac{d^2}{2 \times y^2(t)} \right] \] (3)

As we have considered above, \( \frac{d^2}{y^2(t)} < 1 \) and hence can be ignored in the result.

\[ r(t) \approx y(t) \]

i.e. \( r(t) \approx y_1 + v \times t \)

Since \( y_1 \) is constant and the time interval “t” is also fixed, it can be deduced that the distance is directly proportional to the velocity of the mobile node.

One of the objectives of our research is to predict the time instance the mobile node would reach a point outside the coverage area of the current stationary node. We consider the figure below to further our explanation of this prediction mechanism. We assume that the mobile node is moving with a constant velocity. The connection is initiated when the mobile node enters the coverage area and terminated when it moves out of the coverage area.
We implemented the Dynamic Source Routing scheme in MATLAB to serve as a basis for evaluating the performance improvement using our proposal. The figure shows the network discontinuity observed by the mobile node. We assume that the DSR would converge to obtain an alternate route in a short time period. However in practical scenario it would take a longer time for the network to converge since a route error would be propagated to the originator which would respond with a route request for alternate routes. This procedure requires a substantial amount of time and there is a possibility that the mobile node would be out of range till an alternate route is propagated.

Figure 3. Prediction of Mobile Node Motion

We connect the two end points of the mobile node trajectory to the stationary node placed at (0, 0). Points A and B are on the circle representing the coverage area of the stationary node. These lines result in a triangle \( \triangle OAB \) which can be split into two as \( \triangle OAP \) and \( \triangle OPB \).

In \( \triangle OAB \), \( OA \cong OB \)………………Radius of the circle

\( \therefore \) \( \triangle OAB \) is an isosceles triangle.

\( \angle OBP \cong \angle OBP \) ……………..Isosceles Triangle property

For the included triangles, \( \triangle OAP \) and \( \triangle OPB \)

\( \angle OBP \cong \angle OBP \) …………………as explained above

\( OP \cong OP \)……………………………………. Common side

\( \angle OPA \cong \angle OPB \) ……Perpendicular to the Chord AB

Therefore, \( \triangle OAP \cong \triangle OPB \)….Side–Angle–Side Test

\( \therefore \) \( PA \cong PB \)

This proves that the knowledge of the time period from the instance a mobile node enters within the coverage area of the stationary node and the event it starts moving away from the stationary node can be used to predict the time period after which the mobile node would be out of range.

3. Simulation and Results

Ultra wideband and Cross layering are recent technologies and offer maximum freedom for implementation since they haven’t been standardized. The disadvantage of using such recent technologies is the unavailability of a tool to evaluate the performance metrics in practical scenarios. We used MATLAB as a tool to evaluate the performance of the modified routing scheme. MATLAB was used to perform the simulation of a two hop network with the mobile node as the destination node. The simulation was run over a number of intervals with varying linear motion paths of the mobile node to simulate the performance of the system for random motions. The coverage area of the intermediate nodes was also varied to test the system for degradation in performance due to inter-channel interference and environmental factors.

Figure 4. Normal DSR Operation

The figure shows the mobile node trajectory and the locations of the originator and the intermediate nodes. The lines connecting the nodes signify the presence of network connectivity between the nodes.

Modified DSR uses UWB distance measurement to track the motion of the mobile node. This feature is enabled only for the intermediate nodes. As can be seen in the figure 5 the mobile node has constant connectivity to the network except during the time it is out of network scope. The constant connectivity reduces the overflow of route error and route request packets in the network. It reduces the power consumption of the mobile node since it does not need to search for available networks once the connection is established. This helps the mobile node to conserve energy and operate over a longer span of time.

The number of discontinuities observed by a mobile node can be used as a performance metric to justify the implementation of our routing mechanism. It can be considered as a prediction system which would forewarn the intermediate nodes about possible disconnection and data loss.
The simulations were performed for various test cases to compensate for real time variations in the mobile node motion and the variance in physical parameters.

Table 1. Reduction in observed discontinuities due to modified algorithm

<table>
<thead>
<tr>
<th>Index</th>
<th>Mobile node motion eqn.</th>
<th>Int. Node Range</th>
<th>No. of Int. Node</th>
<th>% Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(x + 2y = 12)</td>
<td>4</td>
<td>7</td>
<td>17.2</td>
</tr>
<tr>
<td>2</td>
<td>(x + y = 10)</td>
<td>4</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>(x + y = 10)</td>
<td>5</td>
<td>5</td>
<td>11.6</td>
</tr>
<tr>
<td>4</td>
<td>(2x + y = 12)</td>
<td>3</td>
<td>5</td>
<td>14.2</td>
</tr>
<tr>
<td>5</td>
<td>(2x + y = 12)</td>
<td>4</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>(x + 2y = 12)</td>
<td>3</td>
<td>5</td>
<td>12.5</td>
</tr>
<tr>
<td>7</td>
<td>(x + 2y = 12)</td>
<td>4</td>
<td>5</td>
<td>12.7</td>
</tr>
<tr>
<td>8</td>
<td>(x + y = 5)</td>
<td>3</td>
<td>5</td>
<td>12.5</td>
</tr>
<tr>
<td>9</td>
<td>(x + y = 5)</td>
<td>4</td>
<td>5</td>
<td>10.3</td>
</tr>
<tr>
<td>10</td>
<td>(2x + y = 12)</td>
<td>4</td>
<td>7</td>
<td>18.6</td>
</tr>
</tbody>
</table>

The simulations were performed for 100 test runs for every Simulation Index. The motion equations mentioned in the table above defined the trajectory followed by the mobile node during the test simulation. The range of the stationary node is assumed to be constant for the current simulation scenario. It has been observed that the net performance degrades with decrementing stationary node range. It can also be observed from the table above that the performance of our recommended algorithm improves significantly as the intermediate node density increases. The intermediate node range is varied to accommodate for the reduction in the transmission power at the intermediate nodes. It can be observed from table 1 that the variation in the intermediate nodal coverage area does not affect the performance of the suggested routing algorithm. Hence, it can be assumed that the routing is adaptive to power variations in the intermediate nodes.

The plot below describes the reduction in the number of disconnections provided by our implementation of our network architecture.

We observe about 20% improvement in the performance of the routing scheme which is quite significant and justifies the overhead that may be required to track the distance of the mobile node. The improvisation means that it would help conserve a significant amount of energy for the mobile node. It would also reduce the number of route request packets generated at every disconnection reducing the network load due to control traffic. This would provide more capacity for the data traffic improving the overall network performance.

4. Conclusion

The modified Dynamic Source Routing mechanism improves the connection to the mobile node and also significantly reduces the power consumed by the mobile node. This approach uses the inherent features of Ultra wideband technology to improve network performance with minimal computational effort.

This theory can be expanded to track the motion for the intermediate nodes. It would be required to consider that the intermediate node would appear to be stationary to a stationary node; however it may be moving along the coverage area pattern of the node. This would not affect the stationary node however it would make the intermediate node move away from the other nodes without providing a forewarning to the stationary node.

It is important to evaluate the exact time instance a route request should be generated for the mobile node. If the request is made too early it would result in a path based on a past location of the mobile node which may be a non optimum path. If the route request is delayed then there is a possibility that the mobile node may be disconnected for some time due to the lack of a valid route.
References


