A Route Selection Approach Based on Neighbor Dependency Estimated by CSI in Multi-hop Wireless Networks

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Abstract. Unreasonable route selection approach in Multi-hop Wireless Networks (MHWNs) may result in continual routing reconstruction, poor utilization of channel bandwidth and high control overhead. How to select a neighboring node as the next hop and how to evaluate the cost of a link will greatly affect the transmission reliability. In wireless communication, the Channel State Information (CSI) refers to channel properties of a link and describes how a signal propagates from the transmitter to the receiver and represents the combined effect of scattering, fading and power decay with distance, which can represent the transmission characteristics of the wireless communication links. According to the neighbor dependency evaluated by CSI based on Exponential Smoothing Method (ESM), a neighbor dependency-based reliable routing algorithm is presented in this paper. Finally, the performance of the reliable routing protocol based on neighbor dependency (RPBND) is tested in OPNET, and compared with the classical AODV algorithm and the improved AODV based on link Cost (CAODV) algorithm. The simulation results show the RPBND protocol has better performance.

Introduction

Multi-hop Wireless Networks (MHWNs) is formed to serve autonomous collection of nodes which communication over wireless links through multi-hop fashion. It has been envisioned for a wide range of application scenarios, such as mobile ad hoc networks (MANETs), wireless mesh networks (WMNs), wireless sensor networks (WSNs), etc.[1]. The MHWNs are adaptable solutions to military and emergency scenarios for solving the problem of instant communication, where the schemes are of rapid deployment and nice connectivity even in complex radio propagation environments. Considering link reliability and path stability can greatly improve the anti-jamming capabilities of routing protocols.

Recent studies on the impact of barrage and jamming to link quality evaluation in MHWNs have shown that the transmission characteristics of links have a significant effect on the stability and reliability of routing protocols [2].

Some studies have shown that the low reliable wireless communication links have complex spatial and temporal characteristics. Many routing protocols are designed to take advantage of the realistic link layer models. For instance, in the early 2007, Khuu et al. [3] proposed that the accumulative of distributed neighbor congestion state, link stability, neighborhood averaging density and delay information should be used for the next hop decision which could improve the stability of routing protocols. However, this method needs to collect the end-to-end transmission information and evaluate the packet dropped rate and the end-to-end delay continuously. T.R. Halford proposed an autonomous cooperative communication scheme with optimized physical layer to improve the robustness of the upper routing protocol [4], but high performance was required for hardware devices. In [5], Azogu et.al. proposed an security metrics to measure the effectiveness of defense mechanisms against jamming attacks and direct a new category of anti-jammer approaches. But it needs communication vehicles equipped with Onboard Equipment (OBE) moving in the infrastructure of Roadside Equipment (RSE) placed along the field of a transportation environment following traffic operation, this anti-jamming scheme is not adaptable to tactical and emergency services scenarios without fixed infrastructure. The SSA protocol used the signal strength to evaluate the link stability, but cannot response to the interruption of the link expeditiously [6]. In the RABR
protocol, the communication nodes need to sample the signal continuously and the link lifetime can be predicted by the distribution of signal intensity [7]. Similar to the LSPMR protocol, by calculating the variance of the signal strength of the received data packet, the stability of the link can be predicted [8]. According to the historical information to evaluate the link stability, this protocol cannot dynamically reflect the topology variability in the electromagnetic interference environment. The QRME protocol relies on GPS or other auxiliary equipment to get the node location, speed and other information to calculate the life time of link and choose a stable path consequently. The disadvantage of this method is that each node needs to be equipped with locating beacon [9]. In the PPC-MAODV routing protocol, a stability metric of relative position change of adjacent nodes was proposed [10]. But these protocols based on node position judgment and forecast need high performance of external equipment and application scenarios.

We investigate the PHY and MAC layer based routing path selection protocol and argue that a definition of neighbor dependency estimated by Channel State Information and a acquisition and evaluation mechanism of channel properties of links based on Exponential Smoothing Method, as this will decrease the unnecessary load on the network, without increasing the size of the control message excessively, compared to the existing schemes, and enables the current node to decide the next relaying hop more precisely than routing protocol based on node dependency not using ESM estimation, compared with our previous studies in [11].

**Exponential Smoothing Estimation of Channel State Information**

Since the characteristics of links have great impact on the performance of routing algorithms, some studies proposed new models to describe the strength of connection between routing nodes based on empirical data. A simple method for calculating node dependency expressed as the Node Degree is to accumulate the number of one-hop connective neighboring nodes observed by the node $i$ was given by S. H. Yook [12]. In [13], the Degree Centrality $K_i$ was proposed, $K_i = \sum_{j \neq i} k_{ij}$, wherein $k_{ij} = 1$ if there is a practical link between node $i$ and $j$, else $k_{ij} = 0$. Although these methods are simple for calculation, it cannot reflect the coupling degree of the node with all its neighbors.

The reliability of the communication is determined by the channel state information. The channel state information will be estimated at the receiver, then quantized and fed back to the transmitter. In this research, it is assumed that the bidirectional equivalent of the short distance multi-hop communication networks, they are all represented by CSI. In [14], the channel state information represented by instantaneous channel gain matrix elements is obtained in Eq.1,

$$h(i, j) = \frac{\gamma[j] \cdot N_0 B}{P_i}, 0 \leq \gamma[j] < \infty$$

(1)

wherein $\gamma[j]$ is the instantaneous receiving SINR, $N_0/2$ is the unilateral power spectral density of AWGN (Additive White Gaussian Noise), $B$ is the estimation of available signal bandwidth and $P_i$ is the calculation of signal power. The power and data rate had been preset when the sending node transmitted a set of short training sequences, so the distribution of $h(i, j)$ is determined by the distribution of the instantaneous receiving SINR.

Channel State Information (CSI) reflects the current state of the link communication. In order to measure the channel state, each node broadcasts a probe packet every 500 milliseconds, this packet header includes the transmitter power value of $P_i$. According to the received probe packet, each neighboring node will reply the detection process in a non-preemptive mode. And the response message includes the value of $\gamma[j]$ which can be calculated according to the Eq. 1. The actual value of CSI can be calculated by channel gain which refers to channel properties of a link and represents the combined effect of scattering, fading and power decay with distance. The total channel gain is
determined by statistical mean in test window period \([0, t-1]\) which saved during the routing maintenance process, and next part is the instantaneous value of the current moment \(t\).

Exponential Smoothing Estimation (Brown 1961) takes the value from the previous period and multiplies it by a smoothing constant \(\alpha \ (0 \leq \alpha \leq 1)\), then adds that amount to the forecast from the previous period times one minus \(\alpha\). We use this calculation method of Exponential Smoothing Estimation for forecasting \(H(i,j)\) in time period \(t\) as follows:

\[
H(i,j) = \alpha \overline{h}_{ins}(i,j,t) + \beta \overline{h}_{stat}(i,j,t-1)
\]  

(2)

Wherein \(H(i,j)\) is the forecasting value of Channel State Information between node \(i\) and \(j\), it can be fed back from every neighbor and be saved by the sending node. \(\overline{h}_{ins}(i,j,t)\) is the statistical mean in test window period, \(h_{ins}(i,j,t)\) is the instantaneous value of the current moment \(t\), which is the basis for the transmitter to adjust the transmit signal in time. \(\alpha\) is the weight of instantaneous value \(h_{ins}(i,j,t)\), and \(\beta\) is the weight of statistical mean \(\overline{h}_{stat}(i,j,t-1)\), \(\alpha + \beta = 1\). For it includes the distribution of environmental fading and the average channel gain, \(H(i,j)\) can be used to evaluate the quality of the links, We can adjust the weights of CSI and evaluate it according to the fading characteristic of the channel.

According to sampling sequence \(X_t\) of RSSI every 500 milliseconds, the MSE (Mean Squared Error) \(A.B(\alpha)\) of ES (Exponential Smoothing) can be obtained as follows,

\[
A.B(\alpha) = \frac{\sum |X_t - S^{(t)}_i|}{n}
\]  

(3)

wherein \(S^{(t)}_i = \alpha X_t + (1-\alpha)S^{(t-1)}_i\), \(S^{(t)}_i\) is the \(t\)th smoothing value. \(S^{(t)}_i\) is the \((t-1)\)th smoothing value and the superscript represents first exponential smoothing. \(\alpha\) is the coefficient of exponential smoothing. Set \(\hat{Y}_t = S^{(t)}_t\), \(\hat{Y}_t\) is represented as the predictive value of the \(t+1\)th smoothing value. By comparing the error of the predicted value \(\hat{Y}_t\) and the measured value under different \(\alpha\), the optimal value \(\sigma\) with minimal Mean Squared Error can be obtained. So \(\alpha\) in Equation 2 can be determined by this method.

**Reliable Routing Protocol based on Neighbor Dependency**

It is assumed that the condition of trusted communication link existing between two nodes is \(H(i,j) > \tau\) during the test window period \(T_u\), where \(\tau\) is the channel gain threshold. Under the same available bandwidth and SINR, the larger the channel gain is, the smaller the power required for the receiver, which means the cost is getting smaller. So the weight of edge link \(w_{ij}\) can be expressed by \(H(i,j)\). In the research of the minimum cost routing, the weight of communication link is the forwarding cost of each node, and the transmission process is changing constantly. Considering the above, \(w_{ij}\) is subject to the following separated constraints.

\[
w_{ij} = \begin{cases} 
\frac{1}{H(i,j)} & H(i,j) > \tau \\
\infty & \text{otherwise}
\end{cases}
\]  

(4)

Because of the random movement of the nodes and the interference change, the node adjacent matrix and the edge link weight matrix both are time-variant. Let \(E\) denotes the set of arbitrary link \(e\) \((i, j)\), let \(S\) be the source and \(D\) be the destination. The Minimum cost routing can be defined as the following linear programming problem.
In the routing decision making of mobile multi-hop network, the links of communication nodes with best channel state condition and optimal connectivity put a higher priority on routing nodes selection, according to the node dependency. That is, we do not only need to estimate the cost of link but also need to judge its stability, and these will improve the reliability of the preferred subset of next hop routing nodes.

**Performance Evaluation**

In order to evaluate the performance of our approach, we compare the RPBND (Reliable Routing Protocol Based on Node Dependency) protocol which presented in this paper with the classical AODV protocol and CAODV (improved AODV protocol based on Forwarding Cost) in the same network environment. The experiments are done in the simulated multi-hop network environment built by OPNET Modeler, 16 wireless nodes are randomly deployed over 5000 m × 5000 m region. Each node has a transmission range of 1000m and uses a DCF MAC protocol. The jamming nodes include the fixed jammer and mobile one with the random movement characteristics. The working mode of jammer is multi-frequency, the interference interval is randomly from 1 to 2 seconds and the interference duration is randomly from 1 to 4 milliseconds. According to sampling sequence $t_X$ of RSSI every 500 milliseconds, the MSE (Mean Squared Error) of ES (Exponential Smoothing) can be obtained in Eq. 3, when the value of $\alpha$ is 0.1, 0.6 and 0.9, respectively.

By comparing the Mean Squared Error of Exponential Smoothing, the result can be obtained which is shown in Fig.1, when the value of $\alpha$ is 0.9, the error is the smallest. Therefore, the smoothing coefficient $\alpha$ will be set as 0.9 for getting the best performance.

![An Exponential Smoothing Method to Determine Smoothing Coefficient](image)

**Data Dropped Rate**

The data dropped rate reflects the performance of the routing protocol whether can adapt to the network state change. The interference may cause the retransmission times to exceed the maximum threshold and result in data dropped. The data dropped rate Performance of the three routing protocols under interference circumstances is show in Fig. 2.
Due to the interference effect, the AODV protocol without consideration of any channel information had the highest data dropped rate for its retransmission exceeding the maximum threshold frequently. The CAODV protocol took into account of the forwarding cost based on link rate, so the data dropped rate is lower than AODV. The RPBND protocol presented in this paper has the best performance of Data Dropped Rate for the effect of interference on channel state information was estimated by receiver as the link weight during routing selection. This metric reflects the reliability of the routing protocol. So the RPBND protocol can ensure more robust path in interference environments.

Wireless Network.Load(bits/sec)

Load analysis is based on the number of control packets or routing packets complete the connection establishment procedure for data delivery in wireless network. If the receiver is found by sender then in that case it also replies to sender for sending data. This graph represents the routing load analysis in case of AODV, CAODV and RPBND in Fig 3.

The greater quantities of routing load will degrade the network performance and affect the data packets delivery. It means the overhead in case of AODV are heavier than other protocols for lack of link quality evaluation. Here we notice that the performance of our proposed protocol RPBND is much better than default AODV. Fig.4 shows the result that the RPBND technique gives better performance and fulfill network requirement for considering the link quality. But it needs more control packets to maintain channel state information acquisition during idle time, the routing load level is higher than CAODV but much lower than default AODV.
Conclusions
In this paper, a route selection approach based on assessment and feedback of Channel State Information is presented for MHWNs. By applying this approach, a reliable routing protocol based on node dependency is proposed in order to facilitate the data transmission in case of link interruption. By analysis and utilization of the exponential smoothing value of Channel State Information, the probability of successful forwarding can be predicted more objectively. The simulation results show that the RPBND protocol we proposed can maintain more reliable performance in highly dynamic interference propagation environments.

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