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Integrated Handoff Management in Cognitive Radio Mobile Ad hoc Networks

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Abstract— **The paper introduces proactive integrated handoff management (IHM) scheme in cognitive radio mobile ad hoc networks (CR-MANETs) through an established route. This scheme considers the primary user (PU) activity, secondary user (SU) mobility and channel heterogeneity in the spectrum handoff decision. To reduce the handoff delay, handoff thresholds are used. When the spectrum handoff cannot be done due to the SU's mobility, a local flow handoff (LFH) is performed to find a node in the vicinity of a potential link breakage where the data flow is transferred to the node. The proposed proactive IHM scheme predicts the cognitive link availability that considers the interference to PUs to estimate the maximum link availability time. The availability time is then used in the channel allocation scheme. The results emphasized on improvement of the route maintenance probability using LFH. It is also verified that the number of handoff needed is significantly decreased using the proposed proactive IHM scheme.**

Keywords—Cognitive Radio, Mobile Ad Hoc Networks, spectrum handoff, spectrum management, spectrum mobility

I. INTRODUCTION

The Dynamic Spectrum Access (DSA) is an approach that permits wireless devices to use the idle frequency bands, also called "spectrum holes" with the enabling technology of Cognitive Radio (CR) [1]. CR changes its transmission parameters based on interaction with the surrounding environment and allows the secondary user (SU) to share the spectrum when the primary users (PUs) are not using these spectrum bands [2]. The spectrum holes shift over time and over space. In a CR system, the shifting of spectrum holes can be defined as spectrum mobility, which is cohesive to spectrum handoff. Spectrum handoff refers to the transfer of an ongoing data transmission of a CR user to an empty spectrum band. Spectrum handoff is challenging in cognitive radio mobile ad hoc networks (CR-MANETs) because of frequent topology variations, limited channel transmission range, and lack of central controlling device.

In heterogeneous networks, channels may be located in vast separated spectrum bands that present remarkable heterogeneity in terms of channel transmission range [3]. When considering the influence of node mobility on the channel availability, the effect of channel heterogeneity becomes more significant. Node mobility and channel heterogeneity lead to frequent spectrum handoff. Thus, it is needed to propose a proper algorithm for integrated handoff management (IHM) in CR-MANETs.

In this paper, the channel availability time is used as the main metric for channel allocation. This parameter is estimated by considering the channel heterogeneity and the SU's mobility. The handoff threshold is used to initiate a handoff procedure. In some cases, the distance between two communicating nodes in a hop belonging to an active route exceeds a given threshold and the channel handoff is not efficient because of the limited channel transmission range. In such cases, the node with the link breakage transfers the routing information to another appropriate node. This mechanism is called local flow handoff (LFH) that aims to find a feasible local route upon link breakage, and transfers the traffic to another stable route based on a prediction. The motivation of this mechanism is to maintain end-to-end connectivity once a route is established for the purpose of sending data.

The rest of this paper is organized as follows. Section II describes the related works. In section III, the IHM scheme is introduced. Section IV presents the numerical results. Finally, Section V concludes the paper.

II. RELATED WORKS

Song and Xie [4, 5] proposed a proactive spectrum handoff configuration based on statistics of observed channel utilization. The network coordination and rendezvous issues were solved in this spectrum handoff scheme without using a common control channel. Duan and Li proposed a spectrum handoff strategy in which the optimal spectrum band was chosen based on a multiplex criterion considering the estimated transmission time, the PU presence probability, and the spectrum availability time [6]. However, channel heterogeneity parameters are not considered in the spectrum handoff. [7] pioneered handoff management in CR-MANETs. Factors and types of mobility were mentioned, which necessitate integrated handoff management in CR-MANETs. The authors also proposed a conceptual model for IHM. The authors of [8] formulated the availability of spectrum bands in

CR-MANETs. They integrated the effects of various events on the spectrum holes availability in CR-MANETs using an analytical model. Although [7, 8] introduced the IHM in CR-MANETs, they did not implement this concept. Therefore, a framework must be introduced for IHM in CR-MANETs. In this paper, the IHM scheme is proposed. In the next section, the proposed IHM scheme is explained.

III. INTEGRATED HANDOFF MANAGEMENT FRAMEWORK

The IHM scheme adapts to unpredictable events, making a decision on the SU's data transmission without causing any interference to the PUs while maintaining the end-to-end connectivity. The proposed IHM scheme is equipped with an algorithm to identify appropriate spectrum bands based on the channel qualities, spectrum and node mobility.

A. System description

The SU is equipped with multi-radio, multi-channel and common control channel (CCC) signaling features. Each SU user has two interface. One of them is set to the CCC to maintain the network connectivity. There are L different channel types in a heterogeneous PU network. The maximum number of channels that can be accessed by the SU at a time is C. The C channels can be defined by the set of **T,** which belong to the PU network**.** These channels are classified into L types according to their different transmission ranges such that the cardinality of $|\mathbf{T}|$=L. Channels with different transmission ranges belong to different sets of spectrum pools. The set of each type can be shown by T_l in which $l = \{1,2, \ldots, L\}$, $|T_l| = C_l$, $\mathbf{T} = \{T_1, \ldots, T_L\}$, and $C = C_1+\ldots+C_L$. Depending on the PU activities, any SU can access up to C channels at any position. The transmission range of channels of type T_l is R_l; by considering the channel transmission range classification, the channel heterogeneity is modeled. Given a pair of transmitter-receiver-capable SUs using a channel of type T_l for communication and with distance between them of less than R_l, when the SUs move and their distance exceeds R_l, the transmitting node must change and choose another channel. In this case, the required channel must have a transmission range longer than R_l. In some cases, the distance between two communicating nodes in a hop belonging to an active route exceeds a given threshold and channel handoff is not efficient because of the limited channel transmission range. In these cases, the node with the link breakage transfers the data flow to another proper node. There are also L types of PU; each of them can work only on a channel of type l. Once a PU of type l becomes active and there is no idle channel of type l, as in the case that an SU has occupied a channel of type l, the SU must vacate the channel and release it to the PU. The IHM considers all the above mentioned handoff types.

B. Channel and local flow handoff prediction

A link is available if the two nodes associated with the link are within the transmission range of each other and out of the interference region of any PU. In terms of transmission range, two different handoff regions are defined. These regions are defined as the preemptive channel handoff region and the preemptive LFH region. As illustrated in Fig .1, the first region is determined based on the channel transmission range which is different for each channel types. The second one is determined by the node transmission range. Because the node transmission range depends on the wavelength of the transmission frequency, there is only one preemptive flow handoff region. Two different handoff thresholds are also defined related to each area. The first handoff threshold related to the preemptive channel handoff region is called the spectrum handoff threshold (SHTH). The second handoff threshold is the LFH threshold (LHTH), which is related to the preemptive LFH region. These handoff thresholds are used to initiate the handoff due to the node mobility and channel quality degradation. As illustrated in Fig. 1, nodes B and F are communicating with each other. When either node B or node F moves such that the current channel cannot support their communication, they must vacate the current channel and transfer their ongoing transmission into another channel with a higher transmission range. When such thing occurs, the local flow handoff is performed.

Different handoff thresholds are related to the signal power threshold. Here, the signal power of hello packets is used to approximate the distance between the transmitter and receiver. Suppose that P_{snd} is the hello packet signal power at the transmitting antenna and P_r is the receiving power at distance r. Based on the [9], the signal power received through free space decreases with distance such that:

$$P_r = \frac{P_{\text{snd}}}{r^n} \tag{1}$$

where, n is a number typically between 2 and 4 depends on the distance [9]. Because the preemptive regions are near the maximum transmission range, the drop in the signal power is modeled to $1/r^4$ throughout these regions:

$$P_r = \frac{P_{\text{snd}}}{r^4} \tag{2}$$

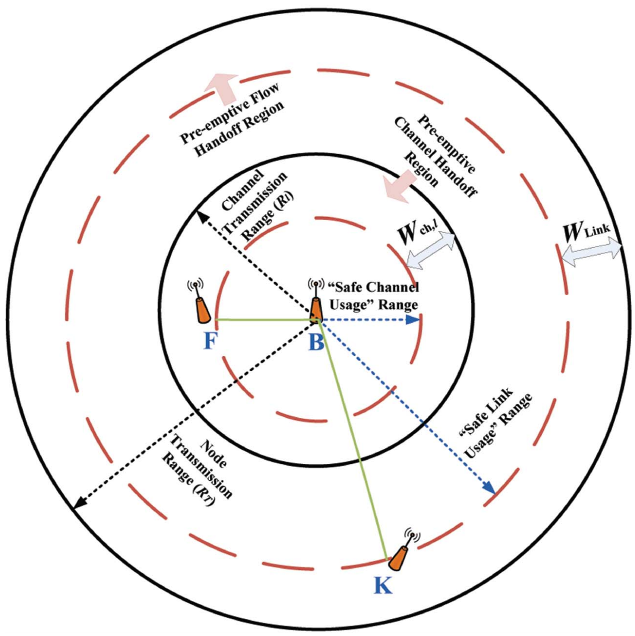

Fig. 1. Different preemptive handoff regions

Based on (2), the signal power threshold for pre-emptive channel handoff (P_{STPCH}) can be expressed as follows:

$$P_{STPCH,l} = \frac{P_{\text{snd}}}{(R_l - W_{ch,l})^4} = \frac{P_{\text{snd}}}{(R_l - (v_{\text{relative}} \times t_{\text{w},l}))^4} \tag{3}$$

where, the $W_{\text{ch},l}$ is the warning distance for nodes communicating on a channel of type l, v_{relative} is the relative speed of nodes, and $t_{\text{w},l}$ is the warning interval. The minimum power received by the receiver, which is the power at the channel transmission range, $P_{CTR,l}$, is expressed as follows:

$$P_{CTR,l} = \frac{P_{\text{snd}}}{R_l^4} \tag{4}$$

The spectrum handoff threshold (*SHTH)* can be described as:

$$SHTH,l = \frac{P_{STPCH,l}}{P_{CTR,l}} = \frac{R_l^4}{(R_l - (v_{\text{relative}} \times t_{\text{w},l}))^4} \tag{5}$$

Similarly, the handoff threshold for the preemptive LFH region (*LHTH*) can be expressed as:

$$LHTH = \frac{P_{SLFTH}}{P_{NTR}} = \frac{R_T^4}{(R_T - W_{link})^4} \tag{2}$$

where P_{SLFTH} is the signal power threshold for preemptive flow handoff and P_{NTR} indicates the minimum power received by the receiver at the node transmission range, R_T. The $t_{\text{w},l}$ which is the interval from the warning till the communication link break off, needs to be greater than or equal to the necessary time for performing the handoff.

C. *Channel usage time prediction*

Using the above handoff prediction scheme with further samples of the transmitted signal, the channel availability time is estimated. Each SU keeps a neighbour signal information table (NSIT). The NSIT contains information about the condition of links with any neighbour. The SU receives and monitors the packets from its neighbours. These packets can be hello packets in the neighbour discovery or data packets in a data transmission. Each node also sends the available channels via hello packets to its neighbours, which are saved in a neighbour information table (NIT). Based on [10], at least three packets are required in order to estimate the channel availability time. Given that at times T_1, T_2 and T_3, node F receives the first, second and third signal with respective power P_1, P_2 and P_3 from node B. The SU registers the signal power strength and reception time for each neighbor in the NSIT. When node F receives packets from node B, it updates its NSIT array such that:

$$P_3 < P_2 < P_1 \text{ and } T_1 < T_2 < T_3$$

When the distance between two SUs is decreasing, P_1 will be higher than P_2 and P_3. In this case, the power strength P_1 is set to the latest signal power value while P_2 and P_3 are set based on the new received signal power. Assume at time T the node F will receive a signal with power equivalent to the threshold P_s, and during time T_1 to T the nodes A and B maintain their speeds and directions. Based on [10], the availability time is expressed as follows:

$$t_{ava} = \frac{\sqrt{b^2 - 4ac} - b}{2a} \tag{7}$$

where:

$$\begin{gathered} \beta = \frac{(\sqrt{P_1P_2}\,t_2 + \sqrt{P_2P_3}\,t_3 - \sqrt{P_1P_3}\,t_3 - \sqrt{P_2P_3}\,t_2)}{(t_2 t_3^2 - t_3 t_2^2)\sqrt{P_2P_3}}, \\ a = t_2\sqrt{P_2P_s}\,\beta\ ,\ b = \sqrt{P_s}((\sqrt{P_1} - \sqrt{P_2}) - t_2^2\sqrt{P_2}\,\beta)\ , \\ c = t_2\sqrt{P_2P_s} - t_2\sqrt{P_1P_2}\ ,\ \ t_2 = T_2 - T_1\ , t_3 = T_3 - T_1\ , t_{avi} = T - T_1 \end{gathered} \tag{8}$$

When the P_s is replaced with the $P_{CTR,l}$, the channel availability time between two communicating nodes for the channel of type l ($t_{ava,l}$) is an estimated value.

D. *PU interference awareness and link availability*

Spectrum holes become unavailable when an SU moves into the interference boundary of an active PU. In terms of th PU's activity, a link is considered available when both nodes associated with this link are out of interference region of any active PU. Hence, the IHM scheme should be aware of the PU's interference boundary and select a suitable intermediate node with a high link availability time to handle the transmission in a LFH. In the IHM, the distances between a SU and PUs are monitored and the link availability is determined before the node moves into the interference area of PUs. The distances between SU and the surrounding PUs are updated dynamically.

To predict the link availability time considering the interference boundary of PUs, the information about the distance between a mobile SU and each PU is obtained through path loss model. During the communication, the movement direction and velocity of mobile nodes can be considered unchangeable in CR networks [11]. Based on [12], the d_{PU}, which shows the link distance between the SU and the PU can be expressed as:

$$d^2_{\text{PU}} = \alpha t^2 + \beta t + \gamma \tag{9}$$

where α, β and γ are constants calculated using three measurement points ($d_{\text{PU},0}$, t_0), ($d_{\text{PU},1}$, t_1) and ($d_{\text{PU},2}$, t_2). If $d_{\text{PU,th}}$ shows the radius of the PU's interference boundary, then the maximum link accessibility period T_{PU} with the PU's interference avoidance counted from t_2 is expressed as:

$$T_{PU} = \begin{cases} \dfrac{\sqrt{\beta^2 + 4d^2_{\text{PU,th}} - 4\alpha\gamma} - \beta}{2\alpha} - t_2 & , \Delta \geq 0 \text{ and } \Delta \geq \beta \\ \infty & , \text{otherwise} \end{cases} \quad (10)$$

where:

$$\Delta = \beta^2 + 4\alpha d^2_{\text{PU,th}} - 4\alpha\gamma. \quad (11)$$

Considering the link accessibility period with the PU's interference avoidance, the most suitable intermediate node is a node with maximum T_{PU}.

E. Channel allocation scheme

In this subsection, the proposed channel allocation scheme is introduced based on the introduced different events affecting the channel availability in CR-MANETs.

The position case D_i is defined as the case in which $R_{l-1} < d_i < R_l$, where d_i is the length of the hop. Hereafter, for the sake of indexing convenience, we refer to D_i as i throughout the paper. To give a fair opportunity to the involved SUs in the longer hops, a weight matrix $\mathbf{W}$ with the size of $L\times L$ is proposed, which considers the hop length or position case i and the channel transmission range. Each element of $\mathbf{W}$ indicates a different location weight and is defined as follows:

$$w_{l,i} = \begin{cases} 0 & \text{for channel of type } l' \text{ and } l' \in \{1,...,l-1\} \\ 1 & \text{for channel of type } l \\ 1/\text{chanel type} & \text{for channel of type } l' \text{ and } l' \in \{l+1,...,L\} \end{cases} \quad (12)$$

The SU's mobility has a significant role on the probability of channel availability in CR-MANETs. Hence, the hop length change, which indicates the SU's mobility, is considered in channel allocation scheme. The parameter $h_{l,i}$ is proposed to show the possibility of using the channel of type l, detected by both nodes in the current hop with position case i. This parameter is defined as follows:

$$h_{l,i} = \begin{cases} 1 & \text{for channel of type } l' \text{ and } l' \in \{l,...,L\} \\ 0 & \text{for channel of type } l' \text{ and } l' \in \{1,...,l-1\} \end{cases} \quad (13)$$

As previously mentioned, there is a number C_l of channels of type l. Each channel of type l is shown by C_{lj} such that $j=\{1, 2\ldots, C_l\}$. The channel j of type l can be used by the nodes belonging to the current hop when it is available for both its member nodes. The parameter η is proposed to show the possibility of using the channel j of type l for communicating in the current hop. This parameter is defined as follows:

$$\eta_{C_{lj}} = \begin{cases} 1 & \text{channel } j \text{ is available for nodes belonging to current hop} \\ 0 & \text{otherwise} \end{cases} \quad (14)$$

To avoid handing off the data transmission to a channel with a short availability time, the channel availability time must be greater than a threshold. Therefore, the parameter ξ is proposed to show the possibility of using the channel of type l for data transmission in the current hop with position case i. The parameter ξ is defined as follows:

$$\xi_{l,i} = \begin{cases} 1 & \text{for } t_{ava,l,i} \geq t_{th} \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

Finally, the channel allocation metric for channel j of type l is defined as follows:

$$AM_{C_{lj}} = (\xi_{l,i}).(\eta_{C_{lj}}).(h_{l,i}).(w_{l,i}).(t_{ava,l,i}) \quad (16)$$

Suppose that $CH_{l,i}$ shows the set of channels of type l detected by both nodes belonging to the current hop with position case i. The set CH_i, which shows all the channels of different L types detected by both nodes belonging to the current hop, can be expressed as follows:

$$CH_i = \cup_{l=1}^{L} CH_{l,i} \quad (17)$$

The set of detected and useable channels for communication in current hop with position case i is defined as follows:

$$CH_{i,usable} = \cup_{l=1}^{L}\left[\bigcup_{C_{lj}\in CH_{l,i}} (C_{lj}\cdot\eta_{C_{lj}}\cdot h_{l,i})\right] \quad (18)$$

In the decision part, the channel j, which maximizes the channel allocation metric, is determined as follows:

$$j^* = \arg\max\left\{AM_{C_{lj}}\right\},\ C_{lj} \subseteq CH_{i,usable} \quad (19)$$

F. Handoff initiation and connectivity management

To maintain end-to-end connectivity, the topological variations and channel quality degradation due to node mobility are addressed using the handoff request (HREQ) packets. On the other hand, the PU handoff request (PU-HREQ) is used to address the variations in spectrum availability because of the PU's activity. The single hop PU-HREQ packet informs the neighbour nodes that the PU's activity has been detected on a special channel, and directs them to select another unused channel for data transmission. On the other hand, the HREQ is applied to inform the next hop node that the current link is breaking due to node mobility.

In terms of the PU-HREQ, once an SU detects the PU's activity on a special channel, e.g., channel C_{lk}, the SU discards all the entries through channel C_{lk} and informs its neighbours that the channel is busy using a PU-HREQ. The PU-HREQ packet contains the available and detected channels of the current SU. The SUs that receive the PU-HREQ invalidate the entries through C_{lk} that involve the PU-HREQ source. Using the NSIT based on the channel allocation scheme, the SU that receives the PU-HREQ finds the channel j

that maximizes the channel allocation metric described in (16). When the optimal channel is found, the node sends a handoff reply (PU-HREP) back. This PU-HREP contains the new channel information to perform handoff and continue the transmission. To consider the topological variation due to node mobility or channel quality degradation, once the SU predicts the handoff, it broadcasts a single-hop channel HREQ (CHHREQ) packet to its next hop node. When the next node receives the CHHREQ packet, it makes a decision using the NSIT, by a method similar to the procedure for PU-HREQ.

In LFH, when a SU as the local source (LS) predicts the presence of next hop node in the preemptive LFH region, it broadcasts a single hop local flow HREQ (LFHREQ) containing the next hop node's ID as the local destination (LD) through the CCC. LFH is performed to find an intermediate node (IN) for handling the data transmission responsibility. The selected node must be located in the transmission range of both nodes involved in current hop with the maximum link accessibility period T_{PU}. A neighbouring node that receives the LFHREQ will search its NIT to determine whether the LD is in its NIT. If node LD has been registered as a neighbour node in its NIT, the IN estimates the T_{PU} with all the active PUs in its surrounding area. It finds the minimum T_{PU} among all the PUs, and it sends the LFH reply (LFHREP) packet back to the LS. The LFHREP contains the minimum T_{PU} of the current node. The LS compares all the T_{PU} information received from its neighbours. Then, it selects the best node (BN) among candidate nodes through which nodes LS and LD can maintain the longest life-time avoiding the PUs interference. Then, LS sends a handoff request (HR) to the local destination through the BN using CCC. The HR contains information such as the ID of the LS, the ID of the LD, and the channel availability list of the current node. Once the BN receives the HR, then:

- Node BN compares its own available channels $C_{ava,BN}$ with the available channels of the LS $C_{ava,LS}$ in HR. The usable channel set in this hop is as follows:

$$CH_{i,usable} = \bigcup_{l=1}^{L} \left[(C_{ava,BN,l} \cap C_{ava,LS,l}) \cdot h_{l,i} \right] \tag{20}$$

- Node BN determines the channel j, which maximizes the channel allocation metric from the channel set $CH_{i,usable}$ using (19).
- Let j be the selected channel, node BN updates HR with its own information, the ID of the node LS, the ID of the node LD, and its available channel list.
- Once the CCC is available, it sends the HR to the LD.

When the LD node receives the HR, similar to the BN, it selects a proper channel for its upper hop. The local destination sends the handoff acknowledgment (HA) packet back to the LS. The HA message sets up a new route, and the routing tables in all three nodes are updated. Once the new route is established, the data flow will be passed along the new route. In the case that the LFH is not possible, the global flow handoff is performed by the source node.

IV. Performance Evaluation

In this section, performance comparisons of three different schemes are conducted using Network Simulator 2 (NS-2) [13]. The total number of available channels, C=10, are classified into two different types C_1=5 and C_2=5. The transmission ranges of different channel types are set to R_1=75 m and R_2=125 m. The mobile SUs are distributed in a network with a 2000 m × 2000 m area, and their speed is set to 3 m/s. The transmission range of the static PUs is set to 200 m, and the PUs' activity is modelled as a two-stage on/off procedure with an exponential distribution with rate parameter λ. Hence, the PU activity time equals $1/\lambda$.

Firstly, the SU's route maintenance probability or handoff blocking probability is investigated. The handoff threshold time is set to 6s, and both the PU's and the SU's arrival rates are set to be 0.25. Channel usage time threshold is also set as 12s. The reactive AODV [14] routing protocol is used for route formation over CR-MANET. Three different handoff management schemes are considered. The first scheme only deploys the spectrum handoff, while the remaining two schemes deploy the IHM in which the LFH is added to the management system. One of these two schemes, reactive IHM (RIHM), does not consider the handoff threshold; whereas PIHM considers the handoff threshold for the preemptive handoff region. Fig. 2 verifies the effect of the LFH on the route maintenance probability. It can be seen that the proposed IHM approach efficiently improves the route maintenance probability. In this approach, the data flow is transferred to the nearby users to keep the communication while the first scheme only uses the spectrum handoff to keep the route. The probability of unsuccessful route maintenance is defined as the probability of spectrum handoff blocking (P_{hb}). Fig. 2 indicates that the spectrum handoff blocking probability in the PIHM scheme is significantly lower than the probability of the spectrum handoff blocking in the scheme deploying only spectrum handoff. This is due to deploying the LFH in PIHM. On the other hand, the handoff blocking probability in the PIHM scheme is lower than the probability of handoff blocking in the RIHM. This is because PIHM scheme performs the handoff proactively. Hence, deploying the PIHM can be more efficient than other schemes.

Fig. 3 shows the SU throughput with various numbers of SUs. In this part, the arrival rate of SU packets is equal to 200 packets per second. The PU's packet has an arrival rate equal to 10 packets per second. It is significant that the throughput of SU transmissions decreases when the number of SUs increases. This is because more SUs result in less opportunities to capture the channel for each SU. In this figure, it is shown that the PIHM scheme outperforms the other two schemes in terms of SU throughput.

Fig. 4 shows the SU throughput under various numbers of PU channels. In this part, the arrival rate of SU and PU packets are the same as in Fig. 3. The number of PU channels varies and is divided into identical numbers of channels belonging to two different types detectable by any SU at any location. The number of SUs in the network is fixed at 50. As the number of PU channels increases, the SUs' throughput increases because more channels can be captured by the SUs for data transmissions. In this figure, the PIHM scheme outperforms two other schemes in terms of SU throughput.

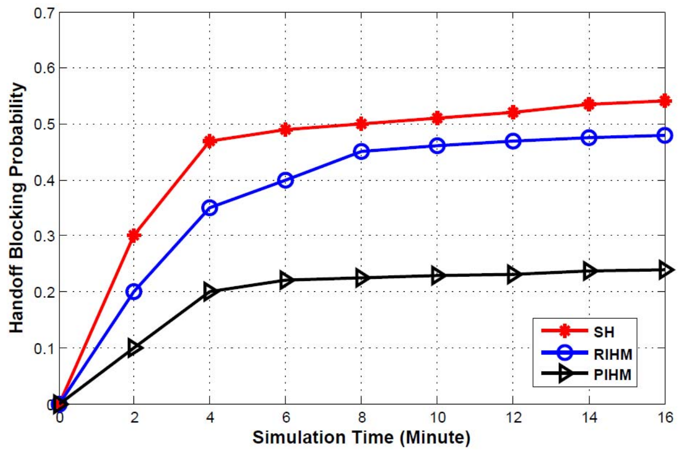

Fig. 2. Comparison of the performance of different handoff management schemes in terms of handoff blocking probability

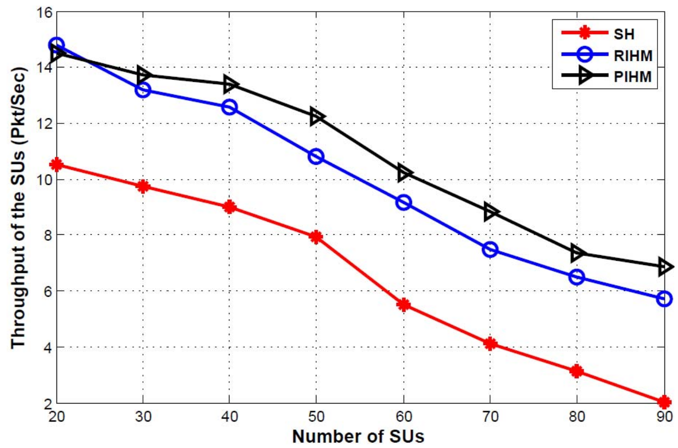

Fig. 3. Comparison of the performance of different handoff management schemes in terms of the SU's throughput vs. the number of SUs

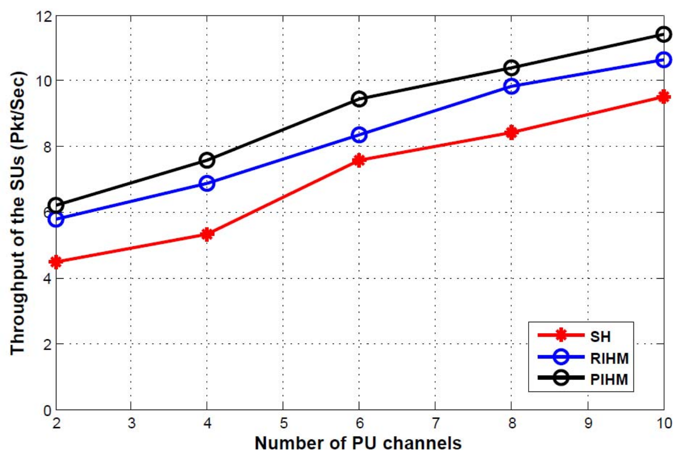

Fig. 4. Comparison of the performance of different management schemes in terms of the SU's throughput vs. the number of PU channels

V. CONCLUSION

In this paper, a proactive integrated handoff management scheme for an established route is introduced. The study reveals that the channel heterogeneity and the SU's mobility must be considered as important factors that affect the performance of handoff management in CR-MANETs. The results show that the proposed IHM scheme achieves more data transmission opportunities, increases the route maintenance probability, and reduces the number of route error requests.

Acknowledgments

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