Channel Allocation Mechanism in C-RAN for Smart Transportation

Isha Bharti[1](✉) and Nishu Gupta[2]

[1] SAP Technology and Innovation, Capgemini, America Inc., Irving 75039, USA
isha.bharti@capgemini.com
[2] College of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur 603203, India

Abstract. Recent developments in vehicular communication demands dynamic channel allocation strategies as well as their implementation in an effective way. A cognitive radio ad hoc network (C-RAN) designed specifically to serve the requirements of smart transportation in a smart city scenario is expected to fulfil these demands. Dynamic utilization of available bandwidth can be accomplished through various C-RAN techniques such as spectrum handover. Such mechanism allows a secondary user (non-owner) to exploit the channel utilities when it is not used by the primary user (licensed owner). In this paper, Dynamic Channel Allocation Mechanism (DCAM) is proposed in order to facilitate reduced handovers in C-RANs. With the help of analytical means, the performance of DCAM is evaluated in terms of various metrics and compared with other similar existing techniques. The results are observed to provide significant improvements which strongly lace the proposed scheme ahead of the others in the mentioned performance metrics.

Keywords: Ad hoc network · Cognitive radio · Dynamic Channel Allocation Mechanism (DCAM) · Handover · Smart transportation

1 Introduction

Classical ad hoc networks are poised to meet a dead-end soon as they follow strategies based on fixed channel assignment. On the other hand, significant regions of licensed bands are underused. Cognitive Radio Ad Hoc Networks (CRANs) can overcome this spectrum scarcity problem. A mobile node dynamically accesses the spectrum holes in licensed bands through Dynamic Spectrum Access (DSA) strategy in CRANs. DSA strategy allows to share the licensed bands to the secondary user (SU) along with the primary user (PU) in an opportunistic manner. Cognitive Radio (CR) [1, 2] is an intelligent radio because it can recognize the underused channel in radio environment. On appearance of PU in the same channel, which is already occupied by SU, then SU shift to other unoccupied channel for the consistent communication. This process of channel switching by SU is referred as spectrum handover.

S. Paiva et al. (Eds.): SmartCity360° 2021, LNICST 442, pp. 321–331, 2022.
https://doi.org/10.1007/978-3-031-06371-8_21

Spectrum handover can be classified into proactive, reactive, hybrid spectrum handover. In proactive approach [3, 4], on the basis of PU traffic model, SU approximates PU arrival. After that SU executes spectrum sensing before handover triggering action happens and vacate the channel. In reactive approach [5, 6], once handover triggering action happens, SU executes spectrum sensing to detect a new channel for spectrum handover. In hybrid approach, SU executes spectrum sensing in proactive way and handover action in reactive way. In all the previously explained handover schemes, handover is executed totally in licensed bands. But none of the spectrum handover approach executes handover in the unlicensed bands. Although, number of channels are limited in unlicensed bands, but they may become vacant and hence, in accordance to [7] probability of availability of unlicensed bands for link maintenance can be taken into consideration. In this paper, we examine the issue of reduction in spectrum handover in CRANs using a new spectrum access technique named Dynamic Channel Allocation Mechanism (DCAM). So, CR ad hoc devices can operate in both licensed and unlicensed spectrum bands by using DCAM spectrum access technique. The performance of DCAM is examined by a wide mathematical model. The remaining paper is structured as follows: Section 2, provides related work done in this field. Section 3 provides an overview of DCAM technique. Section 4 provides proposed model for cognitive radio ad hoc networks. Section 5 provides the link maintenance probability. Section 6 provides the spectrum handover survey. Section 6 provides the performance evaluation of DCAM technique. Section 7, the conclusion of the work is provided.

2 Related Work

In [8], an effect of spectrum handover over the link maintenance of an SU is studied. In [9], for reducing spectrum handovers of SUs, spectrum matching algorithms are used. In [10], a three-dimensional Markov chain model has been used to examine the SUs performance, but here spectrum handover of SUs is not involved to examine SUs performance. Figure 1 explains the concept of cognitive channel switching. Whenever a node finds a channel available and it has data to send, it transmits over the channel.

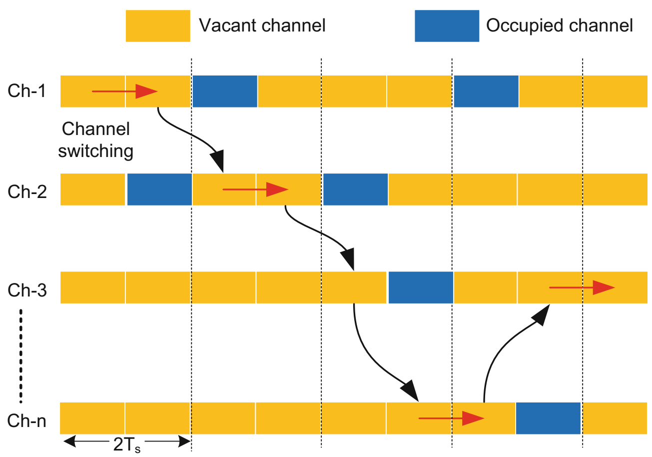

Fig. 1. Concept of cognitive channel switching in vehicular environment

Hence, in all the previous works spectrum handover has not been completely discussed, licensed channels are only used for doing spectrum handovers. The works in [11, 12, 15] are almost relative to our work. In [12] and [15], SUs performance is examined subject to the link maintenance probability and the expected number of spectrum handovers. But in [12] only LCs are used for spectrum handover and in [15] both LCs and UCs are used for spectrum handover. This paper is extension of the work done in [15]. The DCAM technique is explained in the next section.

3 Dynamic Channel Allocation Mechanism (DCAM)

In future, majority of wireless devices will have CR ability and very few wireless devices will be without CR ability. Because licensed bands traverse a large geographic space and considerable parts of the licensed spectrum are underused such as TV bands. So, in CRANs using DCAM technique a SU will use the licensed spectrum as operating spectrum and the unlicensed spectrum as backup spectrum at the instant of PU arrival. At the time of PU arrival, SU should instantly do spectrum handover to unlicensed channels. Here two cases arise: (i) if there are free unlicensed channels available, then SU will shift to a new unlicensed channel and, (ii) if there are no free unlicensed channel available, then SU again do spectrum handover to the licensed channel. For case (ii) again two more sub-cases arise: (a) if there are free licensed channels available, then SU will shift to a new licensed channel and, (b) if there are no free licensed channel available, then SU will halt for a duration with utmost value T_m, So that if any licensed channel becomes free with in duration T_m, then SU will shift to that licensed channel to achieve link maintenance. If no channel becomes free during T_m, then both link maintenance and spectrum handover of SU will fail. In DCAM technique, when channels are available for spectrum handover proactive approach of spectrum handover is used, but for T_m duration reactive approach of spectrum handover is used. Work done in this paper is an addition to the work done in [15].

Different category of users influences the DCAM's performance: (1) primary users (PUs), (2) secondary users (SUs), (3) non-cognitive users (NCUs). NCUs will use only unlicensed bands. The main benefits of utilizing unlicensed bands in DCAM technique are:

- For unlicensed bands all users, whether they are SUs or NCUs, have the identical rights to access them.
- Reduction in spectrum handover count.
- Improvement in link maintenance.

Flowchart of the proposed technique is depicted in Fig. 2.

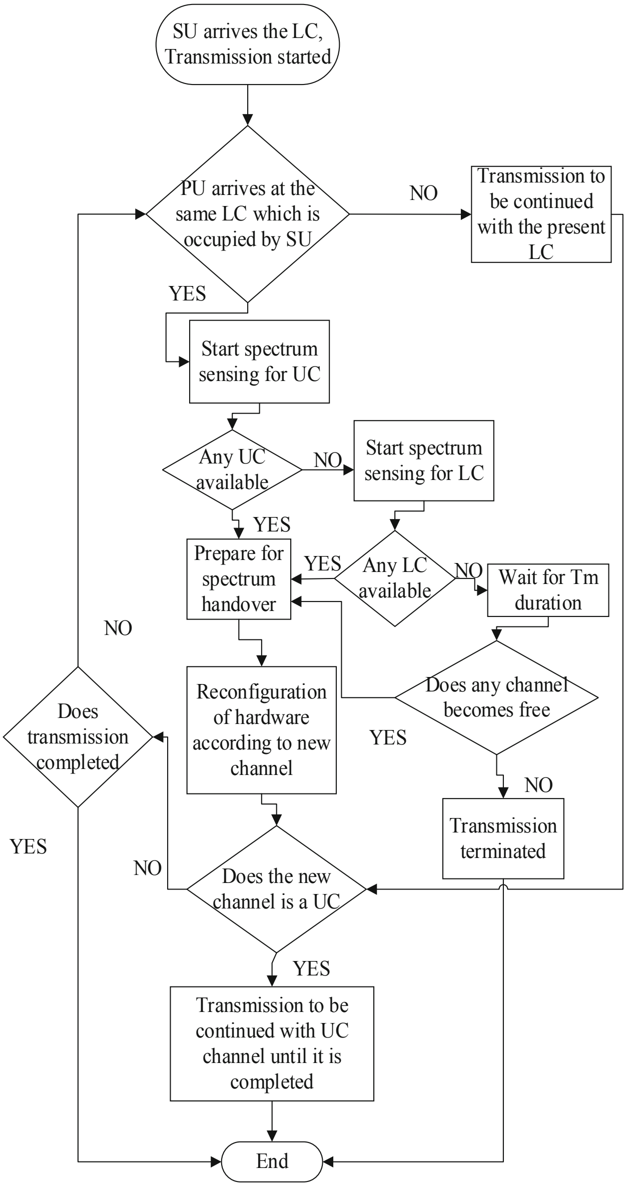

Fig. 2. Flowchart of proposed DCAM technique

NCUs arrivals will affects the SUs link maintenance, so their effects are considered in the next section. DCAM technique is very useful in case when we have to transmit a huge amount of data, i.e., it is better to wait for T_m duration for getting a channel instead of directly terminating the transmission when no free channel is available because if transmission gets terminated than the amount of data which was already transmitted previously has to be retransmitted, which results in wastage of energy as well as time. DCAM technique is very useful for futuristic machine to machine communication.

4 Proposed Model for Cognitive Radio Ad Hoc Networks (CRANs)

This proposed mathematical model discussion by presuming n_1 LCs and n_2 UCs, which are used by nodes of CRANs. The partakers of n_1 LCs will be PUs and SUs, partakers of n_2 UCs will be SUs and NCUs. In case of LCs, SU should leave the channel when licensed user of that channel appears. However, in case of UCs there will be no takeover for any partaker of UCs once it acquires the channel.

4.1 Licensed Users

It is presumed that PU will utilize only licensed channel for its communication motive. It is further presumed that λ_{11} indicates arrival rate of a new PU, whose arrival is a poisson's process. PU inter-arrival time will be denoted by a random variable (RV) $I_{PU_{a'}}$, which will be described as inter-arrival time between $(a^{'}-1)^{th}$ and $a^{'th}$ PU, with general form I_{PU}. Also, PU inter-arrival time I_{PU} obeys an exponential distribution. Hence probability density function (pdf), $f_{I_{PU}}(t)$, of RV I_{PU} will be expressed as $f_{I_{PU}}(t) = \lambda_{11}e^{-\lambda_{11}t}$. Let PU call holding time will be denoted by RV C_{PU} with expectation $\frac{1}{\mu_{11}}$, pdf $f_{C_{PU}}(t)$, cumulative distribution function (CDF) $F_{C_{PU}}(t) = (1 - \Pr(C_{PU} < t))$. The residual call holding time of a PU will be denoted by a RV $R_{PU,a'}$, which will be described as an interval from an in-between instant to the instant of PU work completion, with general form R_{PU}. Using Residual Life Theorem, pdf of residual call holding time of PU will be expressed as $f_{R_{PU}}(t) = \mu_{11}(1 - F_{C_{PU}}(t))$. Assuming ρ_{11} denotes PU traffic density, i.e., $\rho_{11} = {}^{\lambda_{11}}/_{\mu_{11}}$. The variable a' which was defined earlier denotes the number of licensed channels currently occupied by PUs, i.e., $0 \leq a' \leq n_1$. Let P_{11} be a RV representing number of PUs owing to steady state probability distribution, which is denoted by $p_{11_{a'}}$ (where, $0 \leq a' \leq n_1$), given as

$$p_{11_{a'}} = \frac{\rho_{11}^{a'}}{a'!} \frac{1}{\sum_{a'=0}^{n_1} \frac{\rho_{11}^{a'}}{a'!}} \tag{1}$$

4.2 Cognitive Users

Cognitive users are also called secondary users (SUs). It is presumed that SUs will utilize at least one channel for their communication motive. It is further presumed that λ_{22} indicates arrival rate of a new SU, whose arrival is also a Poisson process. Let SU call holding time will be denoted by RV C_{SU} with expectation $\frac{1}{\mu_{22}}$, pdf $f_{C_{SU}}(t)$, CDF $F_{C_{SU}}(t) = \Pr[C_{SU} < t]$ and complementary CDF $\overline{F_{C_{SU}}(t)} = \Pr[C_{SU} > t] = 1 - F_{C_{SU}}(t)$.

When PU arrives, it will choose a specific licensed channel with probability $\frac{1}{n_1 - a'}$, her a' denotes number of licensed channels currently occupied by PUs. If out of $\left(n_1 - a'\right)$ licensed channels, arrived PU selects that channel which is occupied by a SU, then SU will perform a spectrum handover. Let P_{sh} denotes SU handover probability, given as

$$P_{sh} = \left(1 - e^{-\lambda_{11} t}\right) \sum_{a'=0}^{n_1} \frac{1}{(n_1 - a')} p_{11a'}$$

Let P_{22} be a RV representing number of SUs engaged available licensed channels owing to steady state conditional probability distribution, which is denoted by $p_{22_{b'|a'}}\left(0 \le a' \le n_1, 0 \le b' \le n_1 - a'\right)$, where variable b' denotes number of licensed channels occupied by SUs. Then probability $p_{22_{b'|a'}} = \Pr[P_{22} = b'|P_{11} = a']$, will be given as

$$p_{22_{b'|a'}} = \frac{\lambda_{22}^{b'}}{b'!(\mu_{22} + P_{sh})^{b'}} p_{22_{o|a'}} \tag{2}$$

where, $(\rho_{22} = {}^{\lambda_{22}}/_{\mu_{22}})$ and $p_{22_{0|a'}}$ may be provided using standardization condition $\sum_{b'=0}^{n_1 - a'} p_{22_{b'|a'}} = 1$.

4.3 Non-cognitive Users

It is presumed that λ_{33} indicates arrival rate of a new NCU, whose arrival is a Poisson process. NCUs call holding time follows exponential distribution with parameters μ_{33}. Let, P_{33} be a RV representing number of NCUs and SUs engaged available unlicensed channels owing to steady state probability distribution, which is denoted by $p_{33_{a'}}$ (where, $0 \le a' \le n_2$), given as

$$p_{33_{a'}} = \frac{\rho_{33}^{a'}}{a'!} \frac{1}{\left(1 + \sum_{a'=0}^{n_2} \frac{\rho_{33}^{a'}}{a'!}\right)} \tag{3}$$

where, $\rho_{33} = \frac{P_{sh} + \lambda_{33}}{\mu_{22} + \mu_{33}}$.

5 Link Maintenance Probability

To prevent service termination in the course of handover, CR users carry out link maintenance operation to resume communication. Let L_s stands for net link maintenance probability. The probability of successful link maintenance of SU when SU departs from the channel is known as link maintenance probability.

- Over UCs the link maintenance is stated as

$$L_u = P_{sh}(1 - p33_{n_2}).$$

If there are no available unlicensed channels, then also link could be preserved successfully, if there is a free LC. If there is no free LC, link could be still preserved successfully if any LC becomes free within T_m time. If no LC becomes free within T_m time, then link maintenance is terminated. T_s denotes actual waiting time for SU, which is equal to least of every PU call holding times, given as

$$T_s = \min(R_{PU,1}, R_{PU,2}, \ldots, R_{PU,n_1-1}, C_{PU,n_1})$$

- Over LCs the link maintenance is stated as

$$L_l = P_{sh}p33_{n_2}((1 - \Omega) + \Omega\Pr(T_s < T_m))$$

where,

$$\Omega = \sum\nolimits_{a'=1}^{n_1} p11_{a'}p22_{n_1-a'|a'}.$$

On solving, $\Pr(T_s < T_m)$

$$= \Pr\left(\min\left(R_{PU,1}, R_{PU,2}, \ldots, R_{PU,n_1-1}, R_{PU,n_1}\right) < T_m\right)$$

$$= 1 - ((\Pr(R_{PU} > T_m))^{n_1-1}\Pr(C_{PU} > T_m))$$

$$= 1 - (\Phi^{n_1-1}\Psi)$$

where,

$$\Phi = \Pr(R_{PU} > T_m) = 1 - \lambda_{11}\int_0^{T_m}(1 - F_{C_{PU}}(y))dy$$

$$\Psi = \Pr(C_{PU} > T_m) = 1 - \int_0^{T_m} f_{C_{PU}}(y)dy$$

Then, L_l becomes

$$L_l = P_{sh}p33_{n_2}((1 - \Omega) + \Omega(1 - \Phi^{n_1-1}\Psi))$$

- Net link maintenance probability is stated as

$$L_s = L_u + L_l$$

$$L_s = P_{sh}\left(1 - p33_{n_2}\Omega\Phi^{n_1-1}\Psi\right) \tag{4}$$

6 Performance Evaluation of DCAM Technique

In this part, the performance of DCAM is examined in terms of link maintenance probability and expected number of spectrum handovers. The following operative parameters are picked: $\lambda_{22} = 0.5^{SU}/_{sec}$, $\mu_{11} = 0.15^{PU}/_{sec}$, $\mu_{22} = 0.5^{SU}/_{sec}$, $T_m = 1sec$, call holding times of PU and SU follows 2-stage erlang distribution.

The SU link maintenance probability is examined using three distinct scenarios. 6 LCs and 0 UCs are taken in the first scenario. In the second scenario, 6 LCs and 2 UCs are taken, but here T_m is not taken into consideration. In the third scenario (DCAM scenario), 6 LCs and 2 UCs are taken, but here T_m is taken into consideration. In addition, low traffic, moderate traffic and high traffic conditions in UCs due to NCUs are also examined to compare the effect of NCUs on DCAM. Figure 3, 4, 5 shows the link maintenance probability of SU in terms of λ_{11} for low traffic, moderate traffic and high traffic conditions in UCs. In all the three traffic conditions DCAM scenario performs better in comparison to the other two scenarios in terms of link maintenance probability. This can be elaborated as follows. In DCAM, SUs performs the spectrum handovers to the UCs along with the LCs, SUs can halt for T_m duration if there is no free channel available.

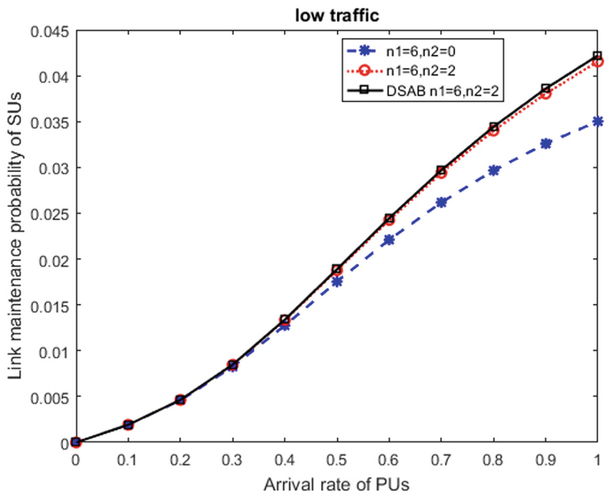

Fig. 3. Link maintenance probability of SUs at low traffic conditions of NCUs

Figure 6 shows the probability for zero spectrum handovers for the DCAM scenario, i.e., probability for $N = 0$. From Fig. 6, it is clear that, as λ_{11} increases, $P[N = 0]$ decreases. This can be elaborated as follows. As λ_{11} increases, number of PUs in LCs increases which leads to increase in the chances for spectrum handover for SUs.

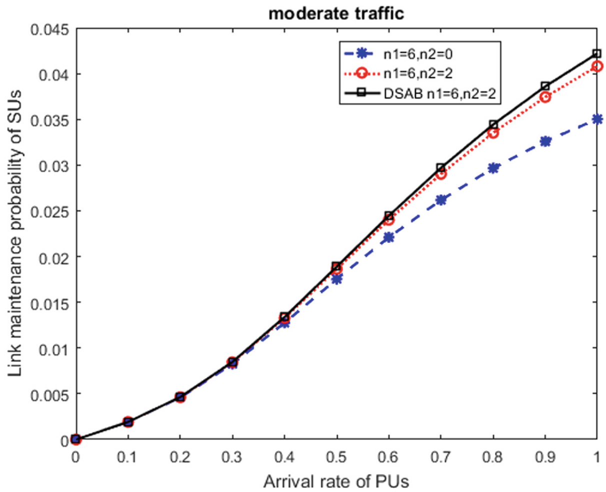

Fig. 4. Link maintenance probability of SUs at moderate traffic conditions of NCUs

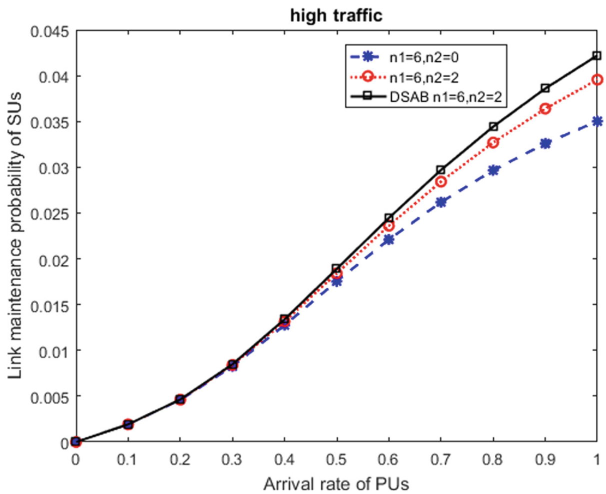

Fig. 5. Link maintenance probability of SUs at high traffic conditions of NCUs

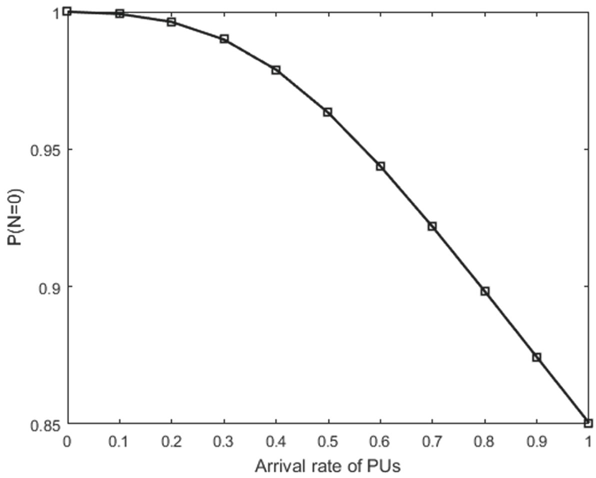

Fig. 6. Probability for zero handovers

7 Conclusion

In this paper, DCAM technique is used for decreasing the number of spectrum handovers in cognitive radio ad hoc networks. The simulation results show an advancement in SUs performance in terms of link maintenance and expected number of spectrum handovers as compared to the previous works. Until now, there have been only a few techniques available for minimizing the spectrum handover, and more studies are needed in these areas.

References

1. Mitola, J., Maguire, G.Q.: Cognitive radio: Making software radios more personal. IEEE Pers. Commun. **6**(4), 13–18 (1999)
2. Wang, P., Chen, C.M., Kumari, S., Shojafar, M., Tafazolli, R., Liu, Y.N.: HDMA: Hybrid D2D message authentication scheme for 5G-enabled VANETs. IEEE Trans. Intell. Transp. Syst. (2020)
3. Tiwari, J., Prakash, A., Tripathi, R.: A novel cooperative MAC protocol for safety applications in cognitive radio enabled vehicular ad-hoc networks. Veh. Commun. **29**, 100336 (2021)
4. Gupta, N., Prakash, A., Tripathi, R.: Medium access control protocols for safety applications in vehicular ad-hoc network: A classification and comprehensive survey. Veh. Commun. **2**(4), 223–237 (2015)
5. Gottapu, S.K., Kapileswar, N., Santhi, P.V., Chenchela, V.K.R.: Maximizing cognitive radio networks throughput using limited historical behavior of primary users. IEEE Access **6**, 12252–12259 (2018). https://doi.org/10.1109/ACCESS.2018.2812743
6. Hu, W., Willkomm, D., Vlantis, G., Gerla, M., Wolisz, A.: Dynamic frequency hopping communities for ecient IEEE 802.22 operation. IEEE Commun. Mag., 80–87 (May 2007)
7. Willkomm, D., Gross, J., Wolisz, A.: Reliable link maintenance in cognitive radio systems. In: Proceedings of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), pp. 371– 378 (2005)

8. Akyildiz, I.F., Lee, W.-Y., Vuran, M.C., Mohant, S.: Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey. Comput. Netw. J. (Elsevier) **50**(13), 2127–2159 (2006)
9. Rawat, D.B., Song, M., Shetty, S.: Resource allocation for cognitive radio enabled vehicular network users. In: Dynamic Spectrum Access for Wireless Networks. SECE, pp. 57–65. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-15299-8_5
10. Chiluveru, R., Gupta, N., Teles, A.S.: Distribution of safety messages using mobility-aware multi-hop clustering in vehicular ad hoc network. Future Internet **13**(7), 169 (2021)
11. Bozkaya, E., Canberk, B.: Robust and continuous connectivity maintenance for vehicular dynamic spectrum access networks. Ad Hoc Netw. **25**, 72–83 (2015)
12. Kalil, M.A., Al-Mahdi, H., Mitschele-Thiel, A.: Analysis of opportunistic spectrum access in cognitive ad hoc networks. In: Al-Begain, K., Fiems, D., Horváth, G. (eds.) ASMTA 2009. LNCS, vol. 5513, pp. 16–28. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-02205-0_2
13. Zhang, Y.: Spectrum handover in cognitive radio networks: Opportunistic and negotiated situations. In: Proceedings of the IEEE International Conference on Communications ICC 2009, pp. 1–6, 14–18 Jun 2009
14. Al-Mahdi, H., Kalil, M., Liers, F., Mitschele-Thiel, A.: Increasing spectrum capacity for ad hoc networks using cognitive radios: An analytical model. IEEE Commun. Lett. **13**(9), 676–678 (2009)
15. Gottapu, S.K., Appalaraju,V.: Cognitive radio wireless sensor network localization in an open field. In: Proceedings of the 2018 Conference on Signal Processing and Communication Engineering Systems (SPACES), pp. 45–48 (2018)
16. Kalil, M.A., Al-Mahdi, H., Mitschele-Thiel, A.: Spectrum handover reduction for cognitive radio ad hoc networks. In: Proceedings of the 7th International Symposium on Wireless Communication Systems ISWCS 2010, pp. 1036–1040, 19–22 September 2010