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QoS-driven pricing policy for cognitive radio networks

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ABSTRACT

Recently, a large amount of spectrum and bandwidth are demanded by mobile network operators (MNOs) in order to obtain the high data rates quality of service (QoS). For optimal spectrum utilization for better efficiency, MNO should handle unused spectrums through a convenient spectrum management. Significantly, MNOs should trade-off among the proposed QoS, service pricing and secondary users' (SUs) satisfaction. In this study, adaptive spectrum management based on the requesting SUs' (RSUs) QoS requirement is proposed in cognitive radio network (CRN). QoS-driven pricing policy is developed so that MNO charges RSUs fairly while improving spectrum utilization and network revenue (NR) efficiency in the long term. Simulation results illustrate the RSUs charging strategy based on dynamic switch system in off-peak and peak hours.

Keywords: Cognitive Radio Networks, Spectrum Management, Pricing Policy, QoS Satisfaction

Bilişsel radyo ağlar için servis kalitesini esas alan fiyat politikası

ÖZ

Son zamanlarda, gezgin ağ operatörleri (MNO), yüksek veri hızı ve servis kalitesi (QoS) sağlamak için yüksek miktarda spektrum ve bantgenişliğine ihtiyaç duymaktadırlar. Spektrumun daha etkin ve optimum kullanımı için MNO, uygun bir spektrum yönetimi üzerinden kullanılmayan bantları sevk ve idare eder. MNO, önerilen servis kalitesi, servis fiyatı ve ikincil kullanıcıların memnuniyeti arasında bir denge kurması çok önemlidir. Bu çalışmada, bilişsel radyo ağlar için, spektrum isteğinde bulunan ikincil kullanıcıların (RSU) servis kalitesine dayalı olan uyarlanır bir servis yönetimi önerilmektedir. MNO, uzun vadede kendi ağ gelirini ve spektrum kullanımını iyileştirirken RSUlar arasında da spektrum kullanımına bağlı olarak adil bir ücretlendirme yapmasını sağlayan QoS-esas alan bir fiyat politikası geliştirilmiştir. Yoğun ve yoğun olmayan saatlerde dinamik anahtarlama sistemine dayalı RSU ücretlendirme stratejilerinin benzetim sonuçları verilmiştir.

Anahtar Kelimeler: Bilişsel Radyo Ağlar, Spektrum Yönetimi, Ücretlendirme Politikası, Servis Kalitesi Memnuniyeti

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1. INTRODUCTION

With the rapid increasing of using wireless communication, requirement for unused radio spectrum has been more significant. Regarded as convenient technology, cognitive radio (CR) offers the possibility to increase the spectrum efficiency. Thereby, CR senses the licensed unused spectrums which are to be used by SUs with optimal QoS Satisfaction Level (QSL) [1], [2].

Spectrum management, sharing, sensing, and moving are intensively researched to provide QSL in different radio access technologies (RATs) [1], [3]. Authors in [4] design data pricing and spectrum allocation algorithm for using in CRN by formulating a Stackelberg game. In [5], Authors proposed an adaptive decision-making optimization scheme (ADMS) for CRN with multiple sub-carriers. In [6], the charging and resource management policy based on reducing the network call blocking ratio (CBR) and the call dropping ratio (CDR) is implemented. In this policy, customer will be charged based on the requesting bandwidth market price (BMP). The cooperative spectrum sharing between the primary user (PU) and CRNs is studied in [7]. In order to benefit from the cooperation between PU and SUs, a Nash bargaining problem is modeled. In [8], User Spectral Efficiency (USE) for cellular networks is presented by using data from 4 different MNOs from different parts of the world. Finally in [9], a spectrum utility model is used to allow a user to make trades among some attributes such as spectrum capacity, monetary cost, and interference potential.

In fact, each RSU has different QoS needs, despite which MNO should find a way to meet their demands. Providing the highest QSL, MNO can attract RSUs to use the spectrum and maintain their demand for the future use. Thus, both RSUs and network attributes should be considered as important parameters in QSL based charging policies which are not completely implemented in the above mentioned works.

As [1] describes about the related open research issue in section VII.A and VII.C., this work presents a QoS-Driven pricing policy to optimize the long term income of the network from MNO's point of view and to motivate RSUs with providing high QSL. The policy charges Accepted RSUs (ARSUs) differently based on their QoS requirement in each time instant. Adaptive charging by MNO will increase the network efficiency as some RSUs may pay a higher price for better service, whereas others may request a lower QoS in return for a cheaper price.

The proposed pricing policy is implemented in our previous framework, Instant overbooking framework for CRN (IOFCR) [10]. The main part of this work is providing optimal spectrum allocation via providing high RSUs QSL and balance the total revenue (TR) in both off-peak and peak hours based on dynamic switch system in the long term [11].

The rest of the paper is organized as follows. In section II, spectrum management system model is presented. In section III, Pricing policy functionality is classified as two main part, IOFCR and QoS-Driven pricing policies. Then, simulation results are shown in section IV. Finally, conclusion and the future works are discussed in section V.

2. SYSTEM MODEL

QSL-Driven pricing policy can allocate the amount of spectrums to RSUs according to their QoS requirement. In this model, the main part of spectrum allocation will be handled by MNO via CRN technology as shown in Fig. 1. According to the spectrum allocation system model (Fig. 1) PUs can use the spectrums whenever sensed. However, SUs should request a spectrum; MNO will check whether there is a free spectrum (FS) bands in the network or not. If available, MNO will allocate spectrum license to ARSUs. For more detail, Fig. 2 illustrates MNO activity at each time instant. Accordingly, each RSU sends its spectrum band request to MNO in each time instant t_i. MNO calculates the FS status that is formulated as

$$FS(t_i) = \varphi - [\, |L_{PU}(t_i)| + |L_{ASU}(t_i)| \,] \qquad (1)$$

where φ is the total number of licensed spectrums kept by MNO, $L_{PU}(t_i)$ and $L_{ASU}(t_i)$ are the lists of PUs and active SUs (ASUs) at time instant t_i, respectively [10].

After FS calculation at t_i, spectrum availability will be evaluated by four main cases:

Case 1: $|L_{RSU}(t_i)| \leq FS(t_i)$

Case 2: $0 \leq FS(t_i) < |L_{RSU}(t_i)|$

Case 3: $0 \leq FS(t_i) < |L_{PU}(t_i)|$

Case 4: $|L_{PU}(t_i)| = \varphi$

According to case1 and 2, in the next step of the Fig. 2, MNO offers the spectrum price based on RSU's QoS requirement. Therefore, MNO should consider some important attributes of RSUs in pricing policy. The pricing policies strategy is introduced in Section 3. If the RSU agrees with the calculated price, spectrum allocation status will be started.

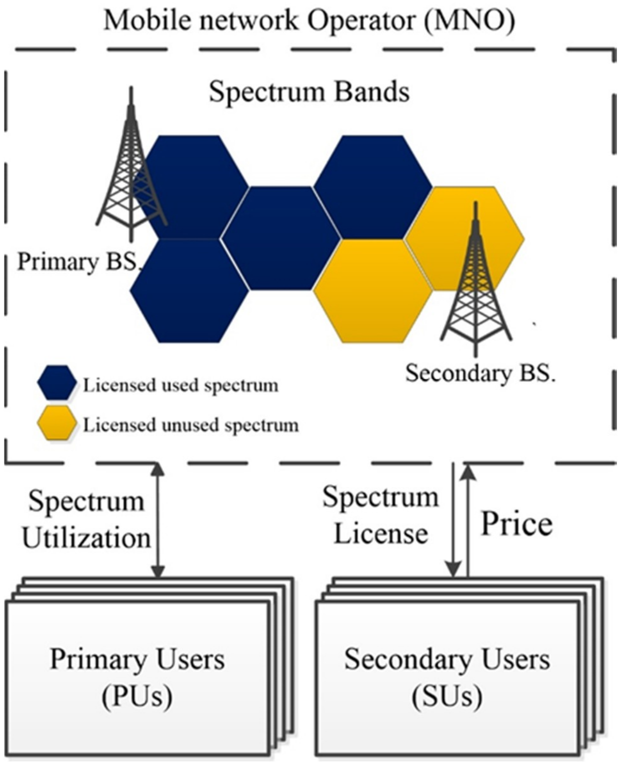

Fig. 1. Spectrum management system model

With regard to the next step in Fig. 2, ASU remain service time (*ASU_RST*) will be calculated for each ASU as follows

$$ASU\_RST(t_i) = TotalReqST - TI(t_i) \quad (2)$$

where *TotalReqST* is the total requested service time by RSU and $TI(t_i)$ shows the i^th^ time instant. If $ASU\_RST(t_i) <> 0$ and case 3 are occurred simultaneously, it means that some PUs are sensed and MNO has to reject some ASUs. But, if $ASU\_RST(t_i)=0$ and case 3 are occurred, MNO will eliminate the finished ASUs (FASUs) from the ASUs' list and PUs kept using the service. All these steps will be continued until the end of the total time intervals (TTI).

3. PRICING POLICY FUNCTIONALITY

3.1. IOFCR Pricing Policies

In our previous works [10], [11], three different pricing policies are implemented as follows:

- Fixed pricing policy: MNO charges all ARSUs with the same price as P_{base}.
- Flexible pricing policy: This policy prioritizes the ARSU spectrum request time, in which booking price varies with respect to request order in time domain. It is denoted by p_{flex} that is set as Equation (3).

$$p_{flex} = \begin{cases} p_{base} * (1 - r), & if\ t_{req} < -\sigma \\ p_{base}, & if\ -\sigma \le t_{req} \le +\sigma \\ p_{base} * (1 + r), & if\ t_{req} > -\sigma \end{cases} \quad (3)$$

where σ is the standard deviation (SD) during t_i and t_{i+1} time instants and t_{req} is the ARSU booking demand time, and r is the booking price constant as $0 \le r \le 1$.

- Adaptive pricing policy: In this policy, the spectrum price is depends on the number of available FSs at time instant t_i. $p_{adaptive}$ is shown as follow
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$$p_{adaptive} = p_{base} * \left(1 + \frac{\varphi}{FS(t_i)*100}\right)^2 \quad (4)$$

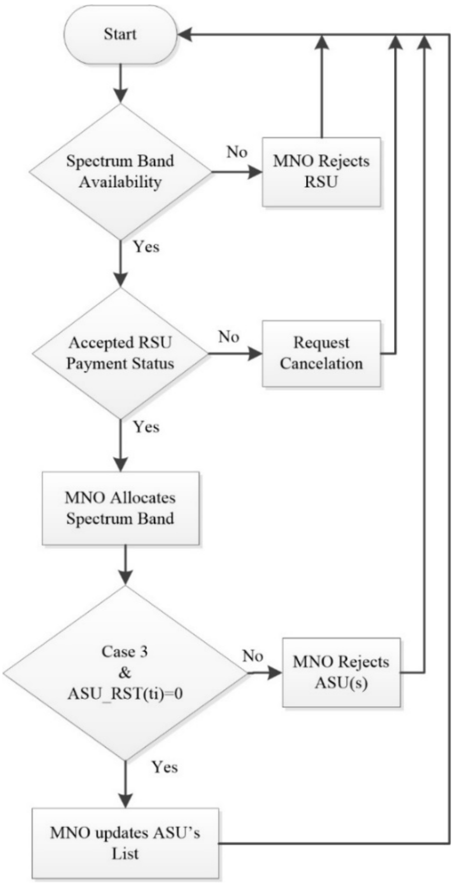

Fig. 2. Time instant spectrum requesting by RSU

3.2. QoS-Driven Pricing Policy

In this section, the QoS-Driven pricing policy is implemented. At first, MNO should consider RSUs attributes. In this model, some important RSU attributes are introduced as follow:

- Requested service time (*ReqST*): shows the amount of time instants RSUs want to be active in the network.
- Requested bandwidth level (*ReqBW*): shows the amount of bandwidth RSUs want to use during *ReqST*. In this paper, bandwidth is classified to four different level as Table 1.
- Rejected ratio (*RR*): This attribute shows the history of how many times RSUs were rejected by MNO in the previous ASUs situation in the network.

Table 1. Bandwidth level classification

Bandwidth level	Bitrate (Mb/s)
Excellent	16
High	8
Normal	4
Low	2

At time instant t_i, each RSU must determine ReqBW, ReqST attributes value during requesting process. On the other hand, if RSUs have RR, it should be defined simultaneously. Because, QoS-Driven Pricing Policy will charge ARSU based on the above mentioned attributes, and also based on the number of RSUs in current time instant that presents the traffic load (TL) of the network. Therefore, MNO should calculate TL in each time instant t_i that is assumed as follows

$$TL(\mathrm{t_i}) = (|L_{PU}(t_i)| + |L_{ASU}(t_i)|/\varphi)\% \quad (5)$$

TL will be classified into two categories such as high and low presenting peak and off-peak hours, respectively. According to this classification, pricing function will be presented as Equation (6) for each ARSU.

$$P_{ARSU_j}(\mathrm{t_i}) = P_{base} \times R_{QoS_j}(\mathrm{t_i}) \quad (6)$$

where P_{base} is the basic default price of each spectrum, the maximum value of j is the total number of ARSU as j= [1,$|L_{ARSU}|$]. On the other hand, $R_{QoS_j}(\mathrm{t_i})$ is the QoS ratio of the *jth* ARSU at time instant t_i that is presented as Equation (7).

$$R_{QoS_j}(\mathrm{t_i}) = \begin{cases} \left(1 + \left(ARSU_j(ReqST) \times ARSU_j(ReqBW)\right)\right) \times \left(1 - ARSU_j(RR)\right), \ if\ TL == high \\ \left(1 + \left(ARSU_j(ReqST) \times ARSU_j(ReqBW)\right)^{\frac{1}{2}}\right) \times \left(1 - (ARSU_j(RR))^2\right), if\ TL == low \end{cases} \quad (7)$$

where it has a direct effect in increasing or decreasing $P_{ARSU_j}(\mathrm{t_i})$ according to the ARSUs QoS requirement via *ReqST*, *ReqBW* and *RR* in both off-peak and peak hours.

When TL is high, the assumption of MNO is that the total revenue (*TR*) is high. RSUs attributes play an important role in calculating the discounted price of ARSUs. On the other hand, when TL is low, it proves that there aren't enough PUs and ASUs in the network. Therefore, the *TR* will probably be low. So, MNO try to decrease the effects of ARSUs attributes in calculating $P_{ARSU}(\mathrm{t_i})$. For instance, if ARSU wants the maximum *ReqBW* and *ReqST* in low TL, MNO charges the ARSU with the lowest observed effect level of its attributes. In this case, though ARSUs pay more, their QSL will be high based on achieving high demanded *ReqST* and *ReqBW*.

Algorithm 1: Dynamic Switch System

while ($t_i < TTI$) begin
  $FS(t_i) \leftarrow \varphi - [|L_{PU}(t_i)| + |L_{ASU}(t_i)|]$;
  if $FS(t_i) > 0$ then
    if *TL is low* then
      ObLimit = *No-ObPolicy* ($FS(t_i)$);
      $P_{ARSU_j}(t_i) = P_{base} \times \left(1 + \left(ARSU_j(ReqST) \times ARSU_j(ReqBW)\right)^{\frac{1}{2}}\right) \times \left(1 - (ARSU_j(RR))^2\right)$;
    elseif *TL is high* then
      switch *Overbooking_Policy*
        case 1
          ObLimit =SL*Policy*($FS(t_i)$);
        case 2
          ObLimit=*RBPolicy* $FS(t_i)$);
        case 3
          ObLimit=*PBPolicy*$FS(t_i)$);
      end switch;
    $P_{ARSU_j}(t_i) = P_{base} \times \left(1 + \left(ARSU_j(ReqST) \times ARSU_j(ReqBW)\right)\right) \times \left(1 - ARSU_j(RR)\right)$;
    end if;
  end if;
end while;

To sum up, Algorithm 1 shows the dynamic switch system depends on off-peak and peak hours based on the *TL*. In off-peak hours, No-ObPolicy functionality is applied [11]. In the proposed method, MNO charges ARSUs in reasonable way via $P_{ARSU}(t_i)$ in comparison with the previous pricing policy. In peak hours, MNO applies overbooking strategy [12], [13] to keep all RSUs in the system for both reasons; SUs satisfaction and increasing the TR. There are three different overbooking policies implemented in IOFCR such as risk based (*RB*), service level (*SL*) and probability based (*PB*) overbooking policies [14]. Algorithm 1 will run until the end of the TTI.

4. SIMULATION RESULTS

In this section, evaluation of different pricing policies in off-peak and peak hours is shown in terms of network revenue (NR) and QoS satisfaction level (QSL). Capacity is set to 100 and the framework is run for 1000 TTL for 20 times. The simulation results show the average standard deviation (SD) and some important parameters in following Table 2 to Table 4 and Fig. 3.

Table 2 presents the TR of the IOFCR pricing policies in comparison with QoS-Driven pricing policy in both peak and off-peak hours. Obviously, TR in off-peak hour is higher than peak hours. In both fixed and flexible pricing policies, TR is the same value as 56500 and 20200 in off-peak and peak hours, respectively (Table 3 will prove the reason for it). However, QoS-Driven TR cannot exceed the IOFCR pricing policies. Because, QoS-Driven policy's strategy is based on RSUs attributes which have a direct effect on ARSUs calculated price. Thus, during the average 1000 TTI, it is almost impossible to show the benefits of the QoS-Driven pricing policy. The benefit of using the proposed pricing policy will be proved in the long term with getting high QSL of RSUs as it is shown in details in Table 3.

Table 3 is captured in the time instant t_{100} which shows the calculated payment price via the four mentioned pricing policies. In fixed pricing policy, all of the payment is fixed as $P_{base} = 100$. In flexible pricing policy, MNO keeps balance among ARSUs based on the SD during t_i and t_{i+1} time instants. However, the TR at the end of the each time instant will be the same for both fixed and flexible pricing policy. As calculated price in adaptive pricing policy is just variable according to each time instant, it is fixed as 106 during t_{100} and t_{101} time instants. Therefore, high RSUs demand in the short term leads to a setback in the system in which adaptive pricing policy works like a fixed pricing policy. Finally, QoS-Driven pricing policy shows the variable prices for each one of ARSUs in t_{100}. For more description Table 4 illustrates ARSUs attributes' value in t_{100}. For instance, the third ARSU has 0.95 RR, 0.25 *Req-BW*, and 0.651 *Req-ST*. The payment price by $ARSU_3$ via QoS-Driven is the minimum one in the Table 3 as 11. Because, $ARSU_3$ had the almost 95% RR and in this case MNO charges ASRU for getting high QSL with the lowest price payment. On the other hand, the first ARSU charges with the maximum price by QoS-Driven policy among all pricing policies as 121. Likewise, $ARSU_1$ had 32% *RR* and he requests almost the high bandwidth in comparison with other ARSUs. In this case MNO charges the highest price for high NR. As a result, MNO keeps balance between NR and QSL in setting appropriate price for each ARSUs.

Finally, Fig. 3 presents the standard derivation (*SD*) of the IOFCR pricing policies in comparison with QoS-Driven pricing policy in 10 time intervals. Fixed pricing policy's SD is 0 as it is fixed during all time intervals. QoS-Driven policy shows the highest SD which proves the variability of the price based on the ARSUs attributes. Even though, QoS-Driven pricing policy's NR does not exceed another pricing policies' NR in 1000 TTI, the benefits of using the proposed policy will be seen in the long term with getting the highest RSUs' QSL.

Table 2. The total revenue (TR) based on PU and SU activity ratio

Pricing Policies		TR based on PU and SU activity	
		Off-Peak hour	Peak hour
IOFCR pricing policies	Fixed	56500	20200
	Flexible	56500	20200
	Adaptive	58740	21242
QoS-Driven		52690	18014

Table 3. Calculated payment price for ARSUs in t_{100}

Pricing Policies	ARSUs payment value according to their ID in t_{100}							
	1	2	3	4	5	6	7	8
Fixed	100	100	100	100	100	100	100	100
Flexible	80	80	100	100	100	100	120	120
Adaptive	106	106	106	106	106	106	106	106
QoS-Driven	121	102	11	30	116	42	104	94

Table 4. ARSUs attributes in t_{100}

ARSUs Attributes	ARSUs Attributes Value according to their ID in t_{100}							
	1	2	3	4	5	6	7	8
RR	0.32	0.19	0.95	0.86	0.09	0.81	0.29	0.28
Req-BW	1	0.5	0.25	0.25	0.25	1	0.25	0.5
Req-ST	0.356	0.118	0.651	0.634	0.713	0.244	0.559	0.047

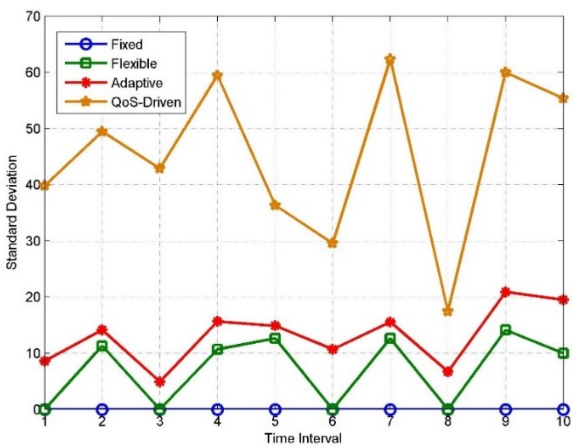

Fig. 3. Standard Deviation (SD) of the pricing policies in 10 time intervals

5. CONCLUSIONS

In this paper, QoS-Driven pricing policy is implemented in dynamic switch for cognitive radio networks. In the proposed method, MNO charges RSUs fairly while improving spectrum utilization and network revenue (NR) efficiency in the long term by providing high QSL. The results of different pricing policies in off-peak and peak hours are given in terms of NR and QSL. In the future work, authors are planning to design different pricing utility functions based on secondary and primary users' QoS requirements. Also, the analysis of implemented pricing policies in different radio access technology (RAT) via licensed shared access (LSA) and cognitive radio (CR) facilities in LTE-A network.

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