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A Novel Spectrum Sharing Scheme using Dynamic Long Short-Term Memory with CP-OFDMA in 5G Networks

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***Abstract*—With the rapid increase in communication technologies, shortage of spectrum will be a major issue faced in the coming years. Cognitive radio is a promising solution to this problem and works on the principle of sharing between cellular subscribers and ad-hoc Device to Device (D2D) users. Existing 5G spectrum sharing techniques work as per a fixed rule and are pre-established. Also, recent game theoretic approaches for spectrum sharing uses unrealistic assumptions with very less practical implications. Here, a novel spectrum sharing technique is proposed using 5G enabled bidirectional cognitive deep learning nodes (BCDLN) along with dynamic spectrum sharing long short-term memory (DSLSTM). Joint spectrum allocation and management is carried out with wireless cyclic prefix orthogonal frequency division multiple access (CP-OFDMA). The BCDLN self-learning nodes with decision making capability route information to several destinations at a constant spectrum sharing target, and cooperate via DSLSTM. BCDLN based on time balanced and unbalanced channel knowledge is also examined. With the proposed framework, expressions are derived for the spectrum allocated to multiple sources to obtain their spectrum targets as a variant of the participation node spectrum sharing ratio (PNSSR). The impression of noise when all nodes broadcast with equal spectrum allocation is also investigated.**

***Index Terms*—5G, Artificial Intelligence, Cognitive Nodes, CP-OFDMA, Deep learning, PNSSR, Spectrum sharing**

I. Introduction

THE enormous demand for localized services has forecasted twofold increase in mobile data traffic compared to the existing fixed IP traffic [1], while the cellular networks fails to deliver this growing demand due to restricted bandwidth and shortage of spectrum [2-5]. Device-to-device (D2D) communication has been proposed and integrated in the next generation mobile network as a possible solution to meet this rising mobile traffic demand. D2D communication allows user to transmit and share cellular data among close proximity users without the involvement of the base stations [6]. Two approaches are employed in D2D to enhance the quality of service: the direct approach and collaborative approach. The cooperative D2D scheme utilizes the cellular user to relay information between base station and end-user to speed up the communication. Decode-and-forward and amplify-and-forward are the prominent relay schemes employed to achieve cooperation among nodes [7]. One of the important factors in multi-hop communication is relay selection. Although various relay selection methods are used to achieve fast data transmission, many of them suffer from limitations in transmission delay, security.

D2D communication happens via the route discovery protocol with increased power savings as base stations are not involved. Once ad-hoc D2D users determine their route, they can share the spectrum with cellular users, i.e. they can operate in the same frequency spectrum as licensed cellular radio network. The existing 5G spectrum sharing has a fixed rule and it is pre-established [8-9]. To overcome the issues, 5G enabled bidirectional cognitive deep learning nodes (BCDLN) along with dynamic spectrum sharing long short-term memory (DSLSTM) is proposed. BCDLN are self-learning proactive and predictive node with decision making capability that creates dynamically adaptable clusters. The joint spectrum allocation and management for 5G access wireless CP-OFDMA communication system with numerous source and multiple destination BCDLN based on time variant and invariant channel knowledge is examined. Each of the BCDLN in the network, sends data to different receivers at a fixed spectrum sharing target and cooperates via DSLSTM with different frequency slots.

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The proposed novel framework for spectrum sharing in the current scenario works around the concept of CP-OFDMA and derive the conditions for the spectrum allocated to multiple sources to achieve their spectrum targets as a function of the participation node spectrum sharing ratio (PNSSR). As the PNSSR decreases between transmit-receive (TR) nodes, channel gain and feedback increase and more information is exchanged between CN nodes creating dynamic spectrum long memory (DSLM) in the forget node (FN), else creating dynamic spectrum short memory (DSSM) in the FNs. Further, the increase in PNSSR matches the spectrum allocation for time variant and time invariant channel state information. For PNSSR less than the required minima, the channel gain and feedback are sufficient as TR nodes employ orthogonal regenerative decode and forwarding (ORDF) and for the PNSSR greater than the required minima the channel gain and feedback is not sufficient as TR nodes employ orthogonal amplify and forwarding (OAF) strategy. The PNSSR resolves the challenge involved in the optimal allocation of the total spectrum of each TR nodes between the transmissions it is assisting, based on time variant and time invariant channel knowledge.

The paper is organized as follows. Section 2 discusses few recent works proposed in 5G spectrum allocation. The proposed method is presented and discussed in section 3. The section presents the discussion on the spectrum sharing framework with BCDLN and DSLSTM along with the theoretical analysis. Different scenarios of spectrum sharing are discussed in this section along with the analysis. The analysis of the proposed method in roundabout network is then presented. The hardware set up and the discussion of results achieved is included in section 5 and finally the paper concludes in section 6 with future research scope. Table 1 presents the list of abbreviations used in the paper.

TABLE 1
LIST OF ABBREVIATIONS

Abbreviation	Definition
D2D	Device to Device
BS	Base Station
BCDLN	Bidirectional Cognitive Deep Learning Nodes
CP-OFDMA	Cyclic Prefix-Orthogonal Frequency Division Multiple Access
DSLSTM	Dynamic Spectrum sharing Long Short-term Memory
PNSSR	Participation Node Spectrum Sharing Ratio
SDN	Software Defined Networking
NFV	Network Functions Virtualization
OAF	Orthogonal Amplify and Forward
ORDF	Orthogonal Regenerative Decode and Forwarding
CN	Cognitive Node
DSLM	Dynamic Spectrum Long Memory
DSSM	Dynamic Spectrum Short Memory
AWGN	Additive White Gaussian Noise
OCF	Orthogonal Compress and Forwarding
USRP	Universal Software Radio Peripheral

II. RELATED WORKS

This section presents the discussion on few recent works in 5G spectrum sharing. In [10], a spectrum sharing method using context information is proposed. Here different user profiles are assumed for different networks and the accuracy of the technique depend on the availability of maximum context information from the network. A discussion on affordable broadband and various aspects for 5G is provided in [11]. The paper also discusses on network infrastructure cost reduction using software defined networking (SDN)/ network functions virtualization technologies (NFV) [12-13]. Most of the recent works in 5G are compatible with IoT, fog and sensor networks [14-17]. Few works have focused on optimization of power and improving efficiency in 5G spectrum allocation [18]. In [19], authors discuss an approach to spectrum sharing using game theory in both licensed and unlicensed bands. Game theory-based solutions for spectrum sharing has many limitations. It assumes that each CN has the knowledge of spectrum sharing strategy of the surrounding CN and the pay-off matrix for the possible solution can be constructed. The assumption is unrealistic with very less practical implications. Other existing 5G spectrum sharing techniques work as per a fixed rule and are pre-established. To overcome these limitations, a novel framework for spectrum sharing is proposed in this paper using 5G enabled bidirectional cognitive deep learning nodes (BCDLN) along with dynamic spectrum sharing long short-term memory (DSLSTM). More efficient spectrum sharing is achieved using the proposed technique.

III. PROPOSED METHOD

This section presents and describes the theoretical analysis of the proposed method DSLSTM integrated with BCDLN. The participating node's spectrum sharing in CP-OFDMA networks with Cognitive Node (CN) behaving as bidirectional deep learning node using proposed DSLSTM architecture, for N=1 to 5 and Cij (i,j = 1 to 5) is indicated in figure 1

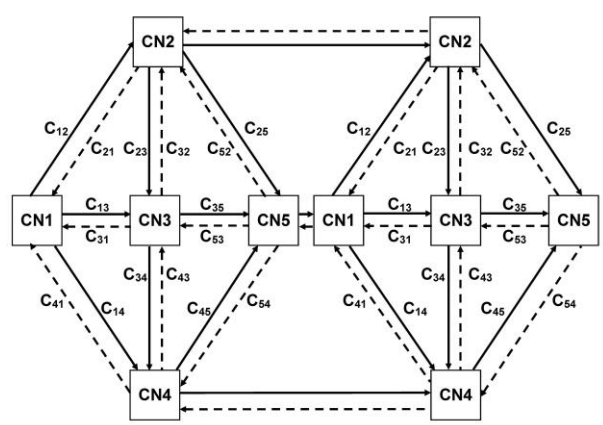

Fig. 1. Dynamic Spectrum Sharing Long Short-Term Memory (DSLSTM) deployment scenario for analysis

Here, each source CN wishes to have a bidirectional communication with its destination CN to obtain their spectrum in terms of PNSSR. The partial knowledge of the spectrum sharing is available with all the CNs. Here the CP-orthogonal transmission between the CNs is considered. When the CN use orthogonal spectrum allocation instead of direct allocation, the destination CNs will not have any spectrum conflict with source CNs. The source CN can directly transmit to the destination CN or via an intermediate CN depending on the spectrum sharing and the bandwidth efficiency. The CN exchanges information based on DSLM or DSSM. The variance N_0 and the additive

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white gaussian noise (AWGN) between the CNs are independent of each other. The spectrum of the node has independent Rayleigh fading, i.e. the weight is varies exponentially with means. The means incorporate the shadowing effect and the spectrum unit between the CNs. The spectrum of CN and the aggregate network spectrum are designated as P_{ij} and P_{total} respectively. The complete spectrum allocation is given by $R^{Tu} = R_{it}+\acute{R}_{jt}$, where R_{it} and $\acute{R}_{jt}$ denotes the spectrum sharing among the distinct CNs. Initially the work is carried out on the smallest total spectrum $P_{totalmin}$ that is needed to assure the total spectrum allocation R^{Tu} for each channel. Then the threshold spectrum is set depending on the PNSSR. If the allocated spectrum is below the threshold spectrum, the PNSSR is less than the required minimum spectrum. The channel weight is large, for this particular DSLM scheme. If the allocated spectrum has a value greater than the threshold spectrum, the PNSSR is greater than required minimum spectrum. The channel weight is small for this particular case of DSSM scheme. The net achievable end to end spectrum allocation is $R^{Tu} = R_{it}+\acute{R}_{jt}$, where R_{it} and $\acute{R}_{jt}$ denotes the spectrum allocation between the different CNs.

A. Different cases in spectrum sharing

Here, the three different cases of spectrum sharing are discussed: direct CN to CN spectrum sharing, spectrum sharing using two forget nodes and fixed spectrum allocation between the CNs.

1) Direct CN to CN spectrum sharing

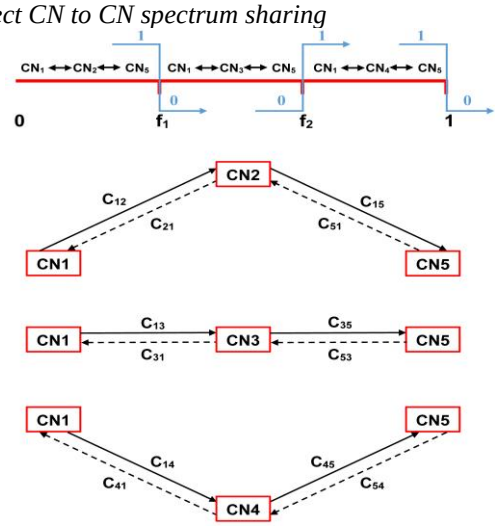

Fig. 2. Direct CN to CN spectrum sharing

The direct CN to CN spectrum sharing is indicated in figure 2. Here the CN1 shares spectrum with CN2 for $0 \le f \le f1$, CN1 shares spectrum with CN3 for $f1 < f \le f2$ and CN1 shares spectrum with CN4 for $f2 < f \le 1$ using Orthogonal Compress and Forwarding (OCF). When the spectrum sharing between CNs is done reliably, the CN nodes decodes and re-encodes the information with the original codebook used in the CN. Transmitter sends the information in the secondary link of the CN. Perfect decidability is not required to pass on the information in the secondary link of the CN using DSLM. Using this strategy of CN, the spectrum allocation can be written as,

$$R_{12}^{(CN_1\to CN_2)} \le \sum_0^{f_1} f_1 \log(1 + C_{12}P_{12}/N_0)$$
$$R_{13}^{(CN_1 \text{ to } CN_3)} \le \sum_{f_1}^{f_2} (f_2 - f_1)\log(1 + C_{13}P_{13}/N_0)$$
$$R_{14}^{(CN_1\to CN_4)} \le \sum_{f_2}^{1} (1 - f_2)\log(1 + C_{14}P_{14}/N_0)$$
$$R_{21}^{(CN_2\to CN_1)} \le \sum_0^{f_1} f_1 \log(1 + C_{21}P_{21}/N_0)$$
$$R_{31}^{(CN_3 \text{ to } CN_1)} \le \sum_{f_1}^{f_2} (f_2 - f_1)\log(1 + C_{31}P_{31}/N_0)$$
$$R_{41}^{(CN_4\to CN_1)} \le \sum_1^{f_2} (1 - f_2)\log(1 + C_{41}P_{41}/N_0) \quad (1)$$

For the transmission of CN1→CN2, the spectrum allocation is f1, CN1→CN3 the spectrum allocation is (f_2-f_1) and for CN1 to CN4 the spectrum allocation is $(1 - f_2)$. Minimum total spectrum allocation convincing the total end to end spectrum rate R^{Tu} needs optimizing the parameters f_1, f_2, P_{12}, P_{13}, P_{14}, P_{21}, P_{31}, P_{41} and is written as,

$$P_{total}^{(C1)} = \min \prod_{f_1,f_2,P_{12},P_{13},P_{14}P_{21},P_{31},P_{41}} (f_1P_{12} + (f_2 - f_1)P_{13} + (1 - f_2)P_{14} + f_1P_{21} + (f_2 - f_1)P_{31} + (1 - f_2)P_{41} \quad (2)$$

such that $R_{1t}+\acute{R}_{1t} \ge R_{Tu}$ and (R_{1t}, $\acute{R}_{1t}$) satisfy eq (1) with,

$$R_{1t} = \min \prod(R_{12}^{(CN_1\to CN_2)}, R_{13}^{(CN_1\to CN_3)}, R_{14}^{(CN_1\to CN_4)}) \text{ and}$$
$$\acute{R}_{1t} = \min \prod(R_{21}^{(CN_2\to CN_1)}, R_{31}^{(CN_3\to CN_1)}, R_{41}^{(CN_4\to CN_1)}) \quad (3)$$

2) Spectrum allocation using two forget nodes

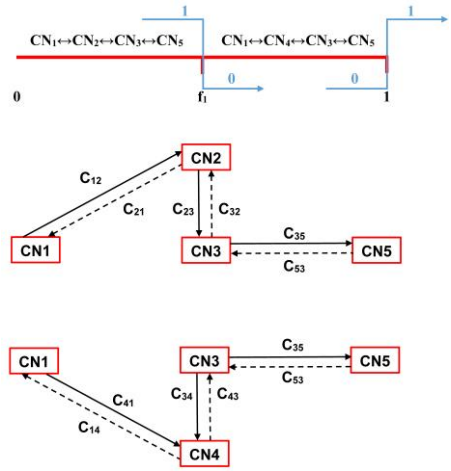

Fig. 3. Spectrum sharing using two forget nodes

In this scenario, the CN source uses two relay CNs to arrive at the expected destination CN and sends the information in improved orthogonal spectrum space. Figure 3 shows the spectrum allocation using two forget nodes. It shows CN1 and CN5 spectrum allocation using CN2, CN3 as forget nodes and CN1 and CN5 spectrum allocation using CN3, CN4 as forget nodes. The end to end spectrum allocation is written as,

$$R_{1235}^{CN_1\to CN_2\to CN_3\to CN_5} \le \sum_0^{f_1} f_1 \log(1 + C_{12}P_{12}/N_0) + f_1 \log(1 + C_{23}P_{23}/N_0) + f_1 \log(1 + C_{35}P_{35}/N_0)$$
$$R_{5321}^{CN_5\to CN_3\to CN_2\to CN_1} \le \sum_0^{f_1} f_1 \log(1 + C_{53}P_{53}/N_0) + f_1 \log(1 + C_{32}P_{32}/N_0) + f_1 \log(1 + C_{21}P_{21}/N_0)$$
$$R_{1435}^{CN_1\to CN_4\to CN_3\to CN_5} \le \sum_{f_1}^{1} (1 - f_1)\log(1 + C_{14}P_{14}/N_0) + (1 - f_1)\log(1 + C_{43}P_{43}/N_0) + (1 - f_1)\log(1 + C_{35}P_{35}/N_0)$$
$$R_{5341}^{CN_5\to CN_3\to CN_4\to CN_1} \le \sum_{f_1}^{1} (1 - f_1)\log(1 + C_{53}P_{53}/N_0) + (1 - f_1)\log(1 + C_{34}P_{34}/N_0) + (1 - f_1)\log(1 + C_{41}P_{41}/N_0) \quad (4)$$

Here, the minimum total spectrum will satisfy the following condition,

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$$P_{total}^{(C3)} = \min \prod_{f_1, P_{12}P_{23}P_{35}P_{53}P_{32}P_{21}P_{14}P_{43}P_{35}P_{53}P_{34}P_{41}} (f_1P_{12} + f_1P_{23} + f_1P_{35} + f_1P_{32} + f_1P_{21} + f_1P_{53} + (1-f_1)P_{14} + (1-f_1)P_{43} + (1-f_1)P_{35} + (1-f_1)P_{53} + (1-f_1)P_{34} + (1-f_1)P_{41}) \quad (5)$$

such that $R_{two\ node} + \acute{R}_{two\ node} \geq R_{Tu}$ and where $R_{two\ node} = \min\prod(R_{1235}, R_{1435})$ and $\acute{R}_{two\ node} = \min \prod(R_{5321}, R_{5341})$

The total orthogonal spectrum is given by,

$$P_{total}^{orth} = \min \prod(P_{total}^{(C1)}, P_{total}^{(C2)}, P_{total}^{(C3)}) \quad (6)$$

For the orthogonal spectrum allocation from CN transmit node to CN receiver node, the smallest total spectrum satisfying complete spectrum R_{Tu} will be the smallest of the total spectrum allocation given in case1-3.

3) Fixed spectrum allocation between the CNs using DSLSTM

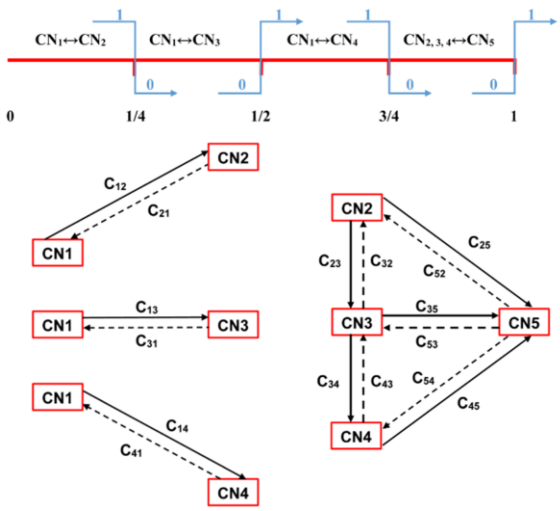

Fig. 4. Fixed Spectrum allocation between the CNs

In this scenario, no relay CN is used between the source and destination CNs. Here the spectrum allocation is fixed and shown in figure 4. The figure shows the source and destination CN for fixed spectrum allocation, CN1 source and CN2 destination for fixed spectrum, CN1 source and CN3 destination for fixed spectrum and CN1 source and CN3 destination for fixed spectrum. The last part of the figure shows source CN2, CN3, CN4 and destination CN5 for fixed spectrum. Here, each CN source communicate with CN destination if the weight of the channel is superior to the channel weight of the rest of paths. The available spectrum is assigned by the CNs with reference to the weight condition of the particular channel for a given total spectrum constraint.

$$R_{12}^{(CN_1 \to CN_2)} \leq \sum_0^{\frac{1}{4}} \frac{1}{4} \log(1 + C_{12}P_{12}/N_0)$$

$$R_{13}^{(CN_1 \text{ to } CN_3)} \leq \sum_0^{\frac{1}{4}} \frac{1}{4} \log(1 + C_{13}P_{13}/N_0)$$

$$R_{14}^{(CN_1 \to CN_4)} \leq \sum_0^{\frac{1}{4}} \frac{1}{4} \log(1 + C_{14}P_{14}/N_0)$$

$$R_{2,3,4}^{(CN_{2,3,4} \to CN_5)} \leq \sum_0^{\frac{1}{4}} \frac{1}{4} (1 + C_{21,31,41}P_{21}/N_0) \quad (7)$$

The spectrum allocation for various paths are stable and identical. Smallest total spectrum satisfying complete spectrum R_{Tu} needs optimal parameter P_{12}, P_{13}, P_{14}, P_{25}, P_{35}, P_{45} and is written as

$$P_{total}^{(C1)} = \min \prod_{P_{12}, P_{13}, P_{14}P_{25}, P_{35}, P_{45}} (\tfrac{1}{4}P_{12} + \tfrac{1}{4}P_{13} + \tfrac{1}{4}P_{14} + \tfrac{1}{4}P_{25} + \tfrac{1}{4}P_{35} + \tfrac{1}{4}P_{45}) \quad (8)$$

such that $R_{1t} + \acute{R}_{1t} \geq R_{Tu}$ and $(R_{1t}, \acute{R}_{1t})$ satisfy eq (1) with

$$R_{1t} = \min \prod(R_{12}^{(CN_1 \to CN_2)}, R_{13}^{(CN_1 \to CN_3)}, R_{14}^{(CN_1 \to CN_4)}, R_{2,3,4}^{(CN_{2,3,4} \to CN_5)}) \quad (9)$$

The CN thus communicates directly with balanced spectrum allocation strategy and extracts dynamic spectrum allotments.

B. Participation node spectrum sharing using DSLSTM

The spectrum sharing occurs in pre-assigned channels. The CN source transmit its information using the spectrum allocated for the first channel and the relay CN retransmits the data in the secondary link using the spectrum allocated for the second channel. The ith sender node having zero-average and unit-variance is represented by s_i, the ith sender's value in the fth frequency slot by $v_i[F] \geq 0$ and the ith sender's transmission in the fth frequency slot by $CN_i[F]$.The jth receiver in the network obtains the signal transmitted by the ith sender in frequency slot f using DSSM given by $rc_{ij}[F]=C_{ij}CN_i[F]+n_{ij}[F]$, where C_{ij} represents (scalar) route magnitude gain in perpendicular medium i between sender's i and j and $n_{ij}[k]$ is the zero-average noise with variance σn2>0.

1) CN source orthogonal DSLSTM protocol

The orthogonal collaborative communication protocol used in the system is given by,

Frequency slot (F1) Frequency slot $(f_2 - f_1)$

Source I $CN_i[f1] = v_i[f_1]si$ $CN_i[f_2 - f_1] = a_i[f_2 - f_1]rc_{ij}[f_2 - f_1]$

Source j $CN_j[f1] = v_j[f_1]sj$ $CN_j[f_2 - f_1] = a_j[f_2 - f_1]rc_{ji}[f_2 - f_1]$

Frequency slot $(1 - f_2)$

Source I $CN_i[(1 - f_2)] = a_i[(1 - f_2)]\ rc_{ij}[(1 - f_2)]\ C_{ij}$

Source j $CN_j[(1 - f_2)] = a_j[(1 - f_2)]rc_{ji}[(1 - f_2)]$

Frequency slot $(1 - f_1)$

Source I $CN_i[(1 - f_1)] = a_i[(1 - f_1)]\ rc_{ij}[(1 - f_1)]$

Source j $CN_j[(1 - f_1)] = a_j[(1 - f_1)]rc_{ji}[(1 - f_1)]$ (10)

The message arriving at the receiver CN nodes using DSLM in the C_{ij} perpendicular medium in frequency slot f is given as,

$$\check{r}c_{ij}[F] = \coprod CijCNi[F] + wij[F] \quad (11)$$

where C_{ij} is the scalar route magnitude gain between the ith subscriber and receiver and $w_{ij}[F]$ is the zero-average noise in this channel with variance σw2>0. The effect of $n_{ij}[F]$ and $w_{ij}[F]$ are contrasting for the frequency slit f as they are computed utilizing DSLM or DSSM method. The receiver CN nodes form the judgement stats for the ith subscriber's message symbol as an integration of the two significant measurements.

$$rc_{ij} = \coprod_{f_1}^{f_2} \check{r}c_{ij}\Gamma_j[f_1]\check{r}c_{ij}[f_1] + \Gamma_i[f_2 - f_1]rc_{ij}[f_2 - f_1]$$

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$$\mathrm{rc}_{ij} = \coprod_{f_1}^{1} \Gamma_i[1-f_1]\,\mathrm{rc}_{ij}[1-f_1] + \Gamma_j[1-f_2]\check{\mathrm{r}}\mathrm{c}_{ij}[1-f_2]$$
$$\check{\mathrm{r}}\mathrm{c}_{ij} = \coprod_{f_1}^{1} \Gamma_j[1-f_1]\,\check{\mathrm{r}}\mathrm{c}_{ij}\,[1-f_1] + \Gamma_i[1-f_2]\,\mathrm{rc}_{ij}[1-f_2] \quad (12)$$

where $\Gamma_i[F]$ and $\Gamma_j[F]$ are the linear fusion of parameters chosen by the receiver to magnify the PNSSR of the verdict stats.

C. Transmit/Receive CN Spectrum and PNSSR Analysis

The organization model and the collaborative communication protocol was described in the previous section. The problem of effectively distributing transmit power is considered in obtaining a pair of stable PNSSR targets, denoted as PNSSR_i and PNSSR_j at the transmitter and the receiver. Without cooperation, the orthogonality of the transmitters is utilized to solve this problem. The PNSSR target will be fulfilled if,

$$\mathrm{P_i} = \mathrm{v_i^2}[f] \geq (\sigma_w^2/\mathrm{C_{ij}^2})\mathrm{PNSSR_i}$$
$$\mathrm{P_j} = \mathrm{v_j^2}[f] \geq (\sigma_n^2/\mathrm{C_{ij}^2})\mathrm{PNSSR_j} \quad (13)$$

where P_i and P_j indicates transmission power of the ith and j^{th} source. For Transmit-Receive CN spectrum analysis, the transmission power source 'i' in frequency slit 'f' is represented as $P_i[F]$.

Source i →

Frequency slot (f1) →

$$\mathrm{P_i}[f_1] = \sum \mathrm{v_i^2}[f_1]$$

Frequency slot $f_2 - f_1$→

$$\mathrm{P_i}[f_2 - f_1] = \sum[f_2 - f_1](\mathrm{C_{ij}^2 v_j^2}[f_2 - f_1] + \sigma_n^2 \quad (14)$$

Source j →

Frequency slot $(1 - f_2)$ →

$$\mathrm{P_j}[(1 - f_2)\ \ ] = \sum \mathrm{a_j^2}[(1 - f_2)\ \ ]$$

Frequency slot$(1 - f_1)$ →

$$\mathrm{P_j}[(1 - f_1)] = \sum[(1 - f_1)](\mathrm{C_{ji}^2 v_j^2}[(1 - f_1)] + \sigma_w^2)\,\mathrm{v_j^2} \quad (15)$$

The aggregate transmission power for source i is given as,

$$\mathrm{P_i}=\sum \mathrm{P}_i[f_1] + \mathrm{P}_i[f_2 - f_1] \quad (16)$$

The absolute transmit power for source j is given as,

$$\mathrm{P_j}=\sum \mathrm{P}_j[f_1 - f_2] + \mathrm{P}_j[1 - f_1] \quad (17)$$

The complete transmit power of all nodes are represented by,

$$\mathrm{P_{total}}=\mathrm{P_i}+\mathrm{P_j} \quad (18)$$

From eq.14 and eq. 15, "collaborative spectrum ratio" criteria is defined for every transmitter in the system. The ith senders' collaborative spectrum ratio is given as the ratio of the spectrum power of the ith source's collaborative retransmission to the spectrum power of the original transmission of source j ($i \neq j$). The collaborative spectrum ratios for the ith source is obtained as,

$$Ж^{i} = \frac{\mathrm{P_i}[f_2-f_1]}{\mathrm{P_j}[1-f_2\,]} = \frac{\mathrm{a_i^2}[f_2-f_1](\mathrm{C_{ij}^2 v_j^2}[1-f_2\,]+\sigma_n^2)}{\mathrm{v_j^2}[1-f_2\,]} \quad (19)$$

for $0 \leq Ж_i < \infty$ and $j \neq i$.

$$Ж_j = \frac{\mathrm{P_j}[1-f_1]}{\mathrm{P_i}[f_1\,]} = \frac{\mathrm{a_i^2}[1-f_1](\mathrm{C_{ij}^2 v_i^2}[f_1\,]+\sigma_w^2)}{\mathrm{v_j^2}[f_1\,]} \quad (20)$$

for i,j $\in$ {1,2,3,4,5} and $0 \leq Ж_j < \infty$ and $j \neq i$. The non-collaborative scenario points to $Ж_i = Ж_j = 0$

D. Spectrum sharing at Destination CN and PNSSR

The next stage in the analysis is to extract equations for the PNSSR of CN nodes at the receiver based on the assumption that the receiver effectively couples the measurements {rc_{ij}, $\check{\mathrm{r}}\mathrm{c}_{ij}$} to PNSSR. Every noise parameter is assumed to mutually exclusive as well as separate from the message, it can be shown that maximum ratio fusing at the receiver magnifies the PNSSR of rc_{ij} and $\check{\mathrm{r}}\mathrm{c}_{ij}$. The maximal ratio merging coefficients can be written as,

$$\frac{\Gamma_i[f_2-f_1]}{\Gamma_i[f_1]} = \frac{\mathrm{C_{ij}v_j}[f_2-f_1]\sigma_w^2}{(\sigma_w^2+\mathrm{C_{ij}^2 v_j^2}[f_2-f_1]\sigma_n^2)}$$
$$\frac{\Gamma_i[1-f_2]}{\Gamma_i[1-f_1]} = \frac{\mathrm{C_{ij}v_i}[1-f_2]\sigma_w^2}{(\sigma_w^2+\mathrm{C_{ij}^2 v_i^2}[1-f_2]\sigma_n^2} \quad (21)$$

The obtained PNSSRs with maximum ratio compounding at the receiver can be expressed as,

$$\mathrm{PNSSR_i} = \bigcup_{f_1}^{f_2} \frac{\mathrm{C_{ij}^2 v_i^2}[f_2-f_1]}{\sigma_w^2} + \frac{\mathrm{C_{ij}^4 v_j^2}[f_1]\mathrm{v_i^2}[[f_2-f_1]]}{\sigma_w^2+\mathrm{C_{ij}^2 v_2^2}[f_1]\sigma_n^2} \quad (22)$$

$$\mathrm{PNSSR_j} = \bigcup_{f_1}^{1} \frac{\mathrm{C_{ij}^2 v_j^2}[1-f_1]}{\sigma_w^2} + \frac{\mathrm{C_{ij}^2 v_i^2}[1-f_1]\mathrm{C_{ij}^2 v_j^2}[1-f_1]}{\sigma_w^2+\mathrm{C_{ij}^2 v_i^2}[1-f_2]\sigma_n^2} \quad (23)$$

Using the values obtained in eq. 22 and eq. 23 into eq. 25 and eq. 26, the PNSSR of each transmitter can be represented as,

$$\mathrm{PNSSR_i} = \bigcap_{f_1}^{f_2} \frac{\mathrm{C_{ij}^2 P_i}[f_1]}{\sigma_w^2} + \frac{Ж_j \mathrm{P_i^2}[f_2-f_1]\mathrm{C_{ij}^4}}{\sigma_w^2(\mathrm{C_{ij}^2 P_i}[f_1]+\sigma_n^2)+Ж_j\mathrm{P_i}[f_1]\mathrm{C_{ij}^2}\sigma_n^2} \quad (24)$$

$$\mathrm{PNSSR_j} = \bigcap_{f_1}^{1} \frac{\mathrm{C_{ij}^2 P_j}[1-f_1]}{\sigma_w^2} + \frac{Ж_i \mathrm{P_j^2}[1-f_2]\mathrm{C_{ij}^4}}{\sigma_w^2(\mathrm{C_{ij}^2 P_j}[1-f_1]+\sigma_n^2)+Ж_i\mathrm{P_j}[1-f_1]\mathrm{C_{ij}^2}\sigma_n^2} \quad (25)$$

The stipulations of the PNSSR targets {$\mathrm{PNSSR_i}$, $\mathrm{PNSSR_j}$} as well as the collaborative ratios { $Ж_i$, $Ж_j$ } completely compute the minimum transmission power and bandwidth for all CN nodes and the peak collaboration between them.

IV. Roundabout Network Scenario

Here the proposed method BCDLN is analyzed in roundabout network scenario. Figure 5 presents the 'n' spectrum sharing nodes placed at identical spectrum units around the circular path. Assume that every CN will successfully relay spectrum information to its 2 neighbors. For example, spectrum f1 can be shared and broadcasted to cognitive node e1 and e2.

Lemma 1: For the roundabout network it is stated,
1. Beyond DSLSTM $T_w \geq n-2$
2. Including DSLSTM $T_{nc} \geq (n-1)/2$.

Proof: Since one spectrum progressively split and relay to its two nearest neighbors, each broadcast spectrum can transfer at most one unit of spectrum to two CN receivers. An 'n-1' BCDLN receivers are there to cover and thus the best spectrum allocation effectiveness can be (n-1)/2 per spectrum unit. When sending out spectrum information, it is considered

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that single BCDLN transmitter is relaying to n-1 BCDLN receivers. The foremost spectrum sharing reaches dual BCDLN destinations. Every added spectrum sharing can donate one spectrum unit to one BCDLN receiver. Based on the scenario of spectrum sending, it is easy to see that a DSLSTM method obtains the limit in *lemma 1*. For DSLSTM, let us examine the following method. The 'n' is considered as even count. Division of 'n' spectrum in two sets F = $\{f_1,.....f_{\frac{n}{2}}\}$ and E ={ $e_1,.....e_{\frac{n}{2}}$ } of size $\frac{n}{2}$ each, such that each spectrum of F has a dual neighboring nodes in E spectrum.

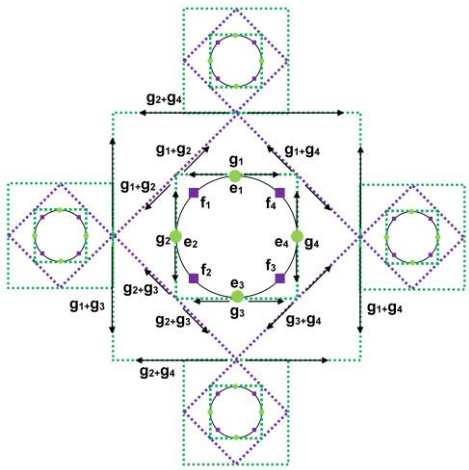

Fig. 5. Roundabout network

For example, figure 5 indicates a circular configuration with n=8 BCDLN nodes. It is sufficient to show that it can share spectrum and telecast in set F to all in sets F and E using $T_{nc} \geq n/2$ spectrum sharing. This procedure is done again uniformly for spectrum sharing in set F. Let $\{x_1 \ldots x_{\frac{n}{2}}\}$ represent the spectrum sharing associated with the nodes in F. Consider the subsequent spectrum sharing theme that advances in 'n/4' steps. Every step has dual phases, where foremost spectrum in group F transmit and spectrum in group E receive and vice versa. The spectrum sharing in different states, state 1 and state k is described below.

State 1: Neighbouring CN node is e_i and neighbouring CN node>1:
In sub state 1, the spectrum in group F split and relay their information to their closest neighbor such that each BCDLN e_i receives g_i and g_{i+1} spectrum as shown in figure 6.
In sub state 2, the spectrum in group E adds the spectrum they receive and broadcast it. For example, BCDLN node f_i receives $g_{i+1}+g_i$ from BCDLN node e_i and $g_{i-1}+g_i$ from BCDLN node e_{t-1}. Thus, BCDLN node fi has the spectrum sharing from sources f_{i-1} and f_{i+1}.

For the state k where the neighboring BCDLN node is 'u' and neighboring BCDLN node>1:

Sub state 1: Each spectrum in group F allocate the sum of the two spectrum units it received in sub state 2, of state 1. Sub state 2: Every spectrum in group E part the sum of the two spectrum units it received in sub state 1, of state 1.

Lemma 2: The DSLSTM deliver the lower bounds in lemma one. Thus

$$\lim_{n\to\infty} \frac{T_{nc}}{T_w} = \frac{1}{2}. \tag{26}$$

Proof: From the preceding analysis it is sufficient to show that algorithm of DSLSTM will complete in at most 'n/4' states. Each state involves 'n' spectrum and every spectrum brings one new sub spectrum unit to two BCDLN receivers. Note that within the last state, second sub state, fewer spectrum sharing's are required, but this does not affect the organization of the result. This DSLSTM method transports 'n/2' spectrum units in 'n $\frac{n}{4}$' spectrum sharing. And thus 'T_{nc} = n/2'. Assume now that every node can share spectrum at a uniform radius of 'u' neighbors, i.e. every spectrum sharing reaches almost '2u' BCDLN nodes. Consider group F spectrum to consist of n/2u transmitters that are '2u' BCDLN nodes apart, and group E spectrum consist of n/2u BCDLN broadcasts. Every spectrum in E is at spectrum unit k from its two nearest neighbors in spectrum group F. The problem is adequately minimized to the u=1 scenario and get directly to the following theorem.

Theorem 1: In a roundabout network where every BCDLN node can really share spectrum at a uniform radius of 'u' BCDLN neighbors,

$$\frac{T_{nc}}{T_w} = \frac{\frac{n-1}{2u}}{\frac{n-1}{u}-1} \approx \frac{1}{2} \tag{27}$$

Note that changing the spectrum sharing to reach further than the direct BCDLN neighbors is non-effective method. It allows to diminish the spectrum sharing by a factor of 'u', but the collected spectrum is proportionate to 'u^l' with a path loss exponent l≈ 2 (depending on the environment).

V. Results and Discussion

The simulation results using the proposed technique are presented in this section. The spectrum allocation in the static CN node with CP-OFDMA using DSLSTM is presented in figure 6. Using the proposed approach, the spectrum is allocated between 500 to 1500 MHz with static CN and varying number of CBs from 0 to 14. Figure 7 and 8 shows the spectrum allocation in static CN node with CP-OFDMA using DSSM and DSLM. Figure 9 shows the spectrum allocation in dynamic CN node with CP-OFDMA using DSLSTM. For static node and dynamic node, the spectrum allocation is optimized with the proposed approach.

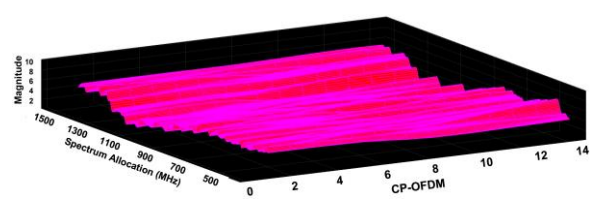

Fig. 6: Spectrum allocation in static CN node with CP-OFDMA using DSLSTM

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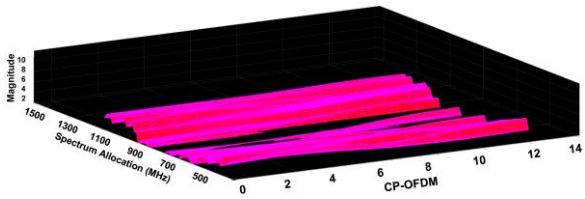

Fig. 7: Spectrum allocation in CN node with CP-OFDMA using DSSM

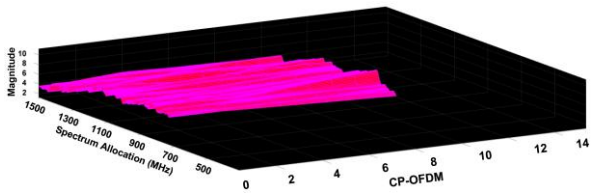

Fig. 8: Spectrum allocation in CN node with CP-OFDMA using DSLM

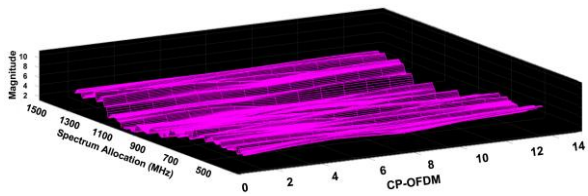

Fig. 9: Spectrum allocation in dynamic CN node with CP-OFDMA using DSLSTM

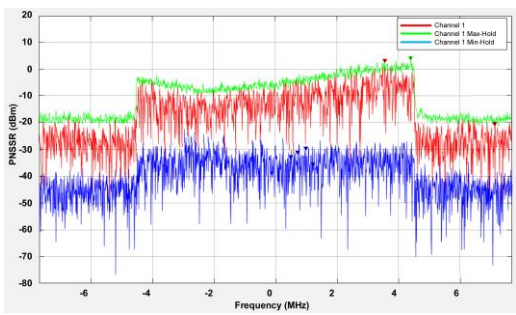

Fig. 10: PNSSR variation with respect to the frequency

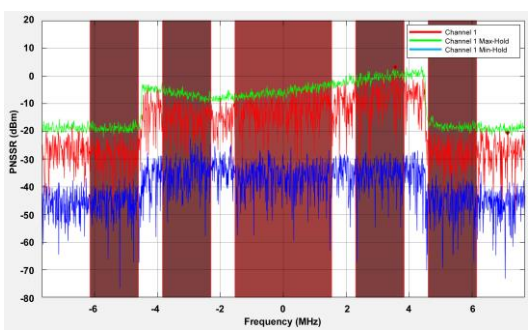

Fig. 11: Spectrum sharing with PNSSR variation

Figure 10 shows the PNSSR variation with respect to frequency spectrum showing the maximum and minimum hold value for channel 1. The PNSSR maximum and minimum values in variation is presented in the figure. Figure 11 shows the spectrum sharing with PNSSR variation. As the PNSSR decreases between transmit-receive (TR) nodes, channel gain and feedback increase and more information is exchanged between CN nodes creating dynamic spectrum long memory (DSLM) in the forget node (FN), else creating dynamic spectrum short memory (DSSM) in the FNs. The PNSSR resolves the challenge involved in the optimal allocation of the total spectrum of each TR nodes between the transmissions it is assisting, based on time variant and time invariant channel knowledge.

VI. Conclusion

A novel spectrum sharing technique in 5G is proposed using cognitive nodes. The self-learning nodes in the system, route information to several destinations at a constant spectrum sharing target, and cooperate via a dynamic spectrum sharing long short-term memory (DSLSTM). Joint spectrum allocation and management is carried out with CP-OFDMA. With the proposed framework, expressions are derived for the spectrum allocated to multiple sources to obtain their spectrum targets as a variant of the participation node spectrum sharing ratio (PNSSR). The PNSSR resolves the challenge involved in the optimal allocation of the total spectrum of each TR nodes between the transmissions it is assisting, based on time variant and time invariant channel knowledge. Theoretical analysis of the proposed method was carried out and results achieved during simulations showed that the proposed method achieved good results in spectrum sharing.

References

[1] Cisco, " Cisco Visual Networking Index: Global Mobile Data Traffic Forecast and Trends,2017–2022White Paper", Cisco, 2019. [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html. [Accessed: 10-Aug-2019].

[2] R. I. Ansari et al., "A New Dimension to Spectrum Management in IoT Empowered 5G Networks," in IEEE Network, vol. 33, no. 4, pp. 186-193, July/August 2019. doi: 10.1109/MNET.2019.1800157

[3] S. K. Haider, A. Jiang, M. A. Jamshed, H. Pervaiz and S. Mumtaz, "Performance Enhancement in P300 ERP Single Trial by Machine Learning Adaptive Denoising Mechanism," in IEEE Networking Letters, vol. 1, no. 1, pp. 26-29, March 2019. doi: 10.1109/LNET.2018.2883859

[4] K. Sharma, T. E. Bogale, L. B. Le, S. Chatzinotas, X. Wang and B. Ottersten, "Dynamic Spectrum Sharing in 5G Wireless Networks with Full-Duplex Technology: Recent Advances and Research Challenges," in IEEE Communications Surveys & Tutorials, vol. 20, no. 1, pp. 674-707, 2018. doi: 10.1109/COMST.2017.2773628

[5] S. Garg, K. Kaur, G. Kaddoum, S. H. Ahmed and D. N. K. Jayakody, "SDN-Based Secure and Privacy-Preserving Scheme for Vehicular Networks: A 5G Perspective," in IEEE Transactions on Vehicular Technology, vol. 68, no. 9, pp. 8421-8434, Sept. 2019. doi: 10.1109/TVT.2019.2917776

[6] D. Verenzuela and G. Miao, "Scalable D2D Communications for Frequency Reuse >> 1 in 5G," in IEEE Transactions on Wireless Communications, vol. 16, no. 6, pp. 3435-3447, June 2017. doi: 10.1109/TWC.2017.2679001

[7] J. N. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," in IEEE Transactions on Information Theory, vol. 50, no. 12, pp. 3062-3080, Dec. 2004. doi: 10.1109/TIT.2004.838089

[8] S. K. Sharma, T. E. Bogale, L. B. Le, S. Chatzinotas, X. Wang and B. Ottersten, "Dynamic Spectrum Sharing in 5G Wireless Networks With Full-Duplex Technology: Recent Advances and Research Challenges," in IEEE Communications Surveys & Tutorials, vol. 20, no. 1, pp. 674-707, 2018. doi: 10.1109/COMST.2017.2773628.

[9] L. Zhang, M. Xiao, G. Wu, M. Alam, Y. Liang and S. Li, "A Survey of Advanced Techniques for Spectrum Sharing in 5G

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Networks," in IEEE Wireless Communications, vol. 24, no.5, pp. 44-51, October 2017. doi: 10.1109/MWC.2017.1700069

[10] P. Kryszkiewicz, A. Kliks, Ł. Kułacz, H. Bogucka, G. Koudouridis and M. Dryjański, "Context-Based Spectrum Sharing in 5G Wireless Networks Based on Radio Environment Maps", Wireless Communications and Mobile Computing, vol. 2018, pp. 1-15, 2018. Available: 10.1155/2018/3217315.

[11] F. Mekuria and L. Mfupe, "Spectrum sharing & affordable broadband in 5G," 2017 Global Wireless Summit (GWS), Cape Town, 2017, pp. 114-118. doi: 10.1109/GWS.2017.8300495.

[12] S. Garg, K. Kaur, S. H. Ahmed, A. Bradai, G. Kaddoum and M. Atiquzzaman, "MobQoS: Mobility-Aware and QoS-Driven SDN Framework for Autonomous Vehicles," in IEEE Wireless Communications, vol. 26, no. 4, pp. 12-20, August 2019. doi: 10.1109/MWC.2019.1800521

[13] V. G. Menon, S. Jacob, S. Joseph and A. O. Almagrabi, "SDN Powered Humanoid with Edge Computing for Assisting Paralyzed Patients," in IEEE Internet of Things Journal. doi: 10.1109/JIOT.2019.2963288S

[14] V. Menon and J. Prathap, "Vehicular fog computing: challenges applications and future directions", in Fog Computing: Breakthroughs in Research and Practice, IGI Global, pp. 220-229, 2018.

[15] Q. Yang et al., "Heterogeneous Semi-Blind Interference Alignment in Finite-SNR Networks With Fairness Consideration," in IEEE Transactions on Wireless Communications. doi: 10.1109/TWC.2020.2965443

[16] Z. Yang, Y. Fang, G. Zhang, F. C. M. Lau, S. Mumtaz and D. B. da Costa, "Analysis and Optimization of Tail-Biting Spatially Coupled Protograph LDPC Codes for BICM-ID Systems," in IEEE Transactions on Vehicular Technology, vol. 69, no. 1, pp. 390-404, Jan. 2020. doi: 10.1109/TVT.2019.2949600

[17] V. G. Menon, S. Jacob and S. Joseph, "Depth Information Enhancement using Block Matching and Image Pyramiding Stereo Vision Enabled RGB-D Sensor," IEEE Sensors Journal, 2019. doi: 10.1109/JSEN.2020.2969324

[18] H. Kour and R. K. Jha, "Power Optimization using Spectrum Sharing for 5G Wireless Networks," 2019 11th International Conference on Communication Systems & Networks (COMSNETS), Bengaluru, India, 2019, pp. 395-398. doi: 10.1109/COMSNETS.2019.8711443

[19] T. Maksymyuk, M. Brych, Y. Klymash, M. Kyryk and M. Klymash, "Game theoretical framework for multi-operator spectrum sharing in 5G heterogeneous networks," 2017 4th International Scientific-Practical Conference Problems of Infocommunications. Science and Technology (PIC S&T), Kharkov, 2017, pp. 515-518. doi: 10.1109/INFOCOMMST.2017.8246452

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