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5G New Radio (5GNR) Performance Optimization for Industrial Application

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Abstract: In modern applications communication through the wireless channels is evolving fast, these services are supporting the important control actions of high-definition data based industrial processes. The fifth-generation (5G) New Radio (5GNR) versions is presently capable of providing flexible control at sub-bandwidth transmission that gives an efficient management of small data packets transmission under industrial automation. While the minimum cycle time to transmit data is serving as a performance metric for provide a robust wireless communication for modern applications, its exploration with 5G technologies is limited. This paper is providing a 5G-NR based industrial automation control scheme with wireless sensor network application that applies a delay optimization algorithm for database channel control. The Ant Colony Optimization (ACO) method, is applied in this work for achieving a reliable minimum cycle time for 5G NR based data transmission.

Keywords: 5G, Ant Colony Optimization (ACO), New Radio, Sensors, Actuators.

1 Introduction

5G based control application in commercial services requires secure correspondence with high efficiency and quality, with high level of flexibility according to user demand. The automation process in the production segment of industrial process targets a generation of 1 to 10 components in milliseconds and consistency rate of more than 99.9999% [1]. The user demand based industrial plant infrastructure are very costly that requires a processing times lower than 1ms [2], [3]. 5G New Radio (NR) belongs to physical layer (PHY) launched under 5G release version of R15. 5G NR supports the flexible operations and packet structure for improving the process execution and enable adaptive transmission of data packets [4]. The majority of research on 5G NR concentrated on analysis of idleness and dependability under the air interface [5, 6] . For most of the high definition applications, the minimum cycle time (MCT) is considered as important metric. The MCT is capable of providing the lower bound of time delay for wireless transmission of data packets [7]. Achieving optimized MCT under specific application at particular information delivered under predetermined number of users (nodes) are the primary objective of wireless communication networks [8].

2 Background

Presently Two alternative channel architectures for 5G services exists and known as 3GPP TR and the NYUSIM [1] for defining constraints under network framework and system performance. Data traffic management and efficient power usage are major focus for research activities and practical utilization in development of wi-fi architecture [2]. Non-Orthogonal Multiple Access (NOMA) is taken as next stage technology that incorporates additional data delivery by inclusion of concepts with energy-space and code-space with superposition coding (SC) [3]. Work on modern innovation provided that permit green 5G application with energy reaping supports for Wi-Fi networks [4].

5G advancements effects in terms of throughput, greenness, and reliability considered for utilization as key issues that incorporates the optimized model based on thoroughly radio asset distribution, and enhancement for IoTs [5].

Encouraging advantages are demonstrated in association with the techniques for assisting 5G to resolve challenges integrate 5G environments with Mobile-Edge Computing (MEC) [6].

A legitimate design presented for network based on 5G, for dealing with portability among unique section to networks, notwithstanding a joint energy and sub channel distribution [7].

A study giving an outline of the cutting edge NOMA exploration and developments projects for examination of challenges in regards to NOMA in 5G [8].

Pareto front multi-objective scheme suggested for accomplishing a steadiness among local area and data focus esteem using pre-select data center areas for the multi-objective model under optimal conditions for the high-quality cell community network divided between Software define network (SDN) and NFV [9].

A strength and range productive IoT network for 5G frameworks proposed where data transmission is imparted to the cell framework for data transmission and lower energy consumption for wireless data transmission [10].

The microstrip radio antenna developed for use in upcoming 5G services in the HFSS software for efficient design and a working range of 28 GHz [11].

Issues inspected for industry services in obtaining high transmission performance to help the industrial IoT (IIoT) [12].

Modern organization necessities examined for a structure that utilized practicality in over 5G services in the US, Europe and four chose nations to figurt out the significance of separating prerequisites and approaches for modern organizations [13].

A vision for a Beyond 5G Wireless Isochronous Real Time (WIRT) frameworks introduced for modern control organizations, intended for supporting quick control applications. WIRT focuses on super remote connections with very low latencies and a wired network independability [14].

Table 1: Existing survey as comparative overview on different technologies involved in 5G.

MIMO	NOMA	5G IOT	5G ML	MEC	5G	Refer-ences
Yes	-	-	-	-	-	[1]
Yes	-	-	-	-	-	[2]
-	Yes	-	-	Yes	-	[3]
-	Yes	-	-	-	-	[4]
-	-	-	-	-	Yes	[5]
-	-	-	-	-	Yes	[6]
Yes	-	-	-	-	-	[7]
Yes	Yes	Yes	-	-	-	[8]
-	-	-	Yes	-	Yes	[9]
-	-	-	-	-	Yes	[10]
-	Yes	-	-	-	-	[11]

3 Approach

5G based multiuser (MU) network works on frequency & time domain simultaneously by applying concept of orthogonal frequency division multiplexing (OFDM).

3.1 OFDM

High transmission rates and the ability to deal with many transmitter signals are provided by OFDM. It has the better quality to reduce the Inter Symbol Interference (ISI) compared to conventional multiplexing techniques. It applies effective frequency division multiplexing (FDM) that minimizes the disturbance across different frequencies to enhance data communication. This is proved to be an ideal scheme for data transmission through wireless network by assisting the prerequisites of efficient frequency band and limit the transmission cost. OFDM can operate in multipath by changing sequential information due to benefits of Fast Fourier Transform (FFT) and Inverse FFT (IFFT).

3.2 Ant Colony Optimization

The behavior of underground insects, including their pheromone-laying and following mechanisms, was thoroughly studied. Insects start to explore the surroundings and eventually find the food supply.

Argentine insects store pheromone during their journey from their food source to their habitat. Initially, each insect selects one of the two paths at random. Regardless, eventually one of the two path exhibits a greater pheromone convergence than the other due to uneven variations, which attracts more underground insects. This increases the amount of pheromone on that path and makes it more appealing, which leads to the settlement as a whole eventually joining to use a similar expansion.

According to autocatalysis, or at the very least, the double-dealing of positive criticism, insects can use this behavior to determine the shortest path between a food source and their habitat. In this case, there are far less stochastic variations in the initial decision, and a subsequent displacement plays a major role: the insects that are randomly selecting the short extension go quickly to the house.

The short extension gets, accordingly, pheromone sooner than the long one and this reality builds the likelihood that further insects select it as opposed to the long one. A model of the behavior expressed as expecting time m1 insects have utilized the principal extension and m2 the subsequent one, the likelihood p1 for an insect to pick the main path is

$$p_1 = \frac{(m_1+k)^h}{(m_1+k)^h+(m_2+k)^h} \quad (1)$$

where boundaries k and h are to be fitted to the exploratory information — clearly, p2 = 1 − p1 . Monte Carlo reenactments showed an excellent fit for k ≈ 2 and h ≈ 2. In ACO, various virtual subterranean insects construct answers under simulation algorithm for the considered improvement main concern and trade data on the nature of these arrangements through a correspondence plot that is suggestive of the one taken on by genuine insects.

3.3 Proposed Work

5G services consist of a subcarrier in the frequency domain called a resource element (RE) and OFDM data in the time domain. 5G NR communication frameworks, operating under LTE and Wi-Fi(R), have mostly adopted OFDM as a multi-transporter regulation technique. Its many benefits include reduced channel latency, effective execution, and tunable frequency space. Its drawbacks are frequently disregarded, such as the decreased effectiveness brought on by larger side-lobe frequency band curves and the stringent synchronization requirements. To get around some of these limitations, new methods are being investigated for 5G NR correspondence frameworks.

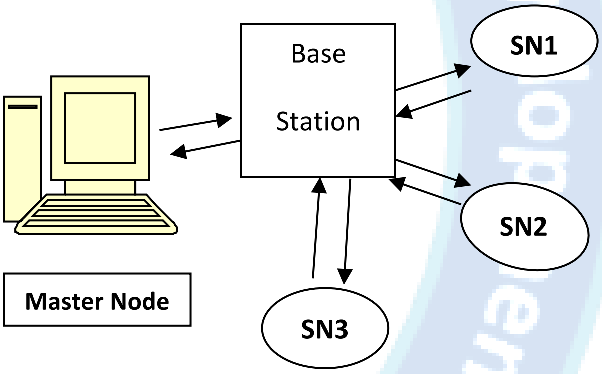

Fig. 1 Industrial communication network based on 5G NR.

A 20 MHz channel transfer speed LTE architecture, for example, uses 100 asset blocks, each with 12 subcarriers, at a 15 kHz individual subcarrier frequency. Ten percent of the dispensed range is used in this way, resulting in packet losses. Additionally, each OFDM data set's cyclic prefix of 144 or 160 samples results in an additional ~7% productivity loss, for a total loss of 17 percent in possible extraterrestrial proficiency.

Applications must be able to manage higher data rates, lower dormancy, and more effective range use in order to comply with the ITU standards for 5G NR designs. This work presents an analysis and comparison of the innovative balancing technique called ACO based Multi-Carrier OFDM and OFDM inside a conventional system.

3.4 ACO-OFDM 5G NR Multi-Carrier Modulation

The ACO improvement issue determines the fundamental reliable transmission capacity to carry a single bundle while modifying the number of OFDM images in the time domain.

To verify the packet error rate (PER) requirement in relation to the data transmission speed, adaptability, and coding scheme, we use MATLAB simulation. The required transmission bandwidth (Wt) is not entirely determined, and the mix of modulation order (M) and coding rate (C) changes at each site and for various boundaries and payloads, from high request to low. With FBMC (Filter Bank Multi-transporter) balances, ACO OFM 5G NR is seen as a speculative Filtered OFDM. Groups of subcarriers (sub-groups) are separated using ACO OFM 5G NR, whereas the whole band is separated in filtered OFDM and individual subcarriers are separated in FBMC.

This subcarrier block enables one to shorten the channel length in contrast to FBMC. Similarly, as QAM is compatible with existing MIMO systems and possesses orthogonal symmetry (as opposed to FBMC), it may be utilized with ACOOFDM 5G NR at all times. Within the whole band of subcarriers (N), there exist subgroups. Every subband has the right number of subcarriers, and not every subgroup should be used for a given transmission. An N-point IFFT with zeros inserted for the unallocated transports is recorded for each subband.

Each subband is divided by a channel of length L, and responses from the different subgroups are merged. In order to minimize the number of out-of-band transmission symbols, the separation is performed. This method employs a similar channel for all subbands, even if individual subbands may use distinct channels. A specified side-curve decreasing Chebyshev window is used to channel the IFFT yield per subband.

An FFT-based ACO fundamental get handling for OFDM as the final result. The subband separation increases the time window for the FFT operation to the force-of-two length that follows. The recurrence frequency of each subcarrier primary curve is compared to the other's. It is common practice to adjust the combined effect of the channel and the subband separation using per-subcarrier leveling. In this model, just the subband channel is leveled because no channel impacts are displayed. The received signals are subjected to noise addition in order to get the best SNR.

3.5 Minimum Bandwidth for Reliability Contraints

The performance of the packet error rate (PER) can be used to evaluate reliability. Numerous factors, including as the number of antennas, coding, modulation, payload length, and signal-to-noise ratio (SNR) value, all have an impact on the PER. The SNR value is further affected by the transmitted power P_{TX}, pathloss P_L, and transmission bandwidth for one packet Wt

$$SNR = \frac{P_{TX}.PL}{N_0.W_t} \qquad (2)$$

where N_0 = kB, where kB is the Boltzmann constant and is the temperature assuming that all OFDMA slave node use the same numerology parameter and do not interfere with one another, interference is not taken into account. Wt is the only variable that affects latency and reliability performance in addition to determining the frequency and time domain resource array structure. Therefore, we first determine the minimum bandwidth required to convert one packet into different quantities of OFDM symbols Nsymb and obtain a PER lower than 10-6 using the solution to the following optimization problem:

$$\min_{M,C} W_t$$
$$s.t.\, N_{symb}.RB.12 \geq \frac{L}{M.C} + N_{sc,DMRS}^{RB}\,.RB \qquad (3a)$$
$$RB = g(W_t, \mu) \qquad (3b)$$
$$PER(L, M, C, SNR, N_{RX}) < 10^{-6} \quad (3c)$$

Equation (3a) states that the RBs in a packet must be large enough to map the modulated data subcarriers and DMRS. This is calculated by multiplying the total number of OFDM symbols (Nsymb) by 12 RBs. The potential RBs given Wt and SCS that correspond to the chosen are shown in equation (3b) above. Wt causes a rise and decrease in the quantity of RBs. Equation (3c) indicates how the adjustment of M and C to meet the PER requirement will impact the value of Wt from Equations (3a) and (3b) (3c) [15 -20].

Larger M and C in particular can be used to meet the PER requirement with high SNR or NRX at the receiver side. Furthermore, a smaller channel bandwidth and fewer data subcarriers spread across fewer symbols are assigned to data bits. Conversely, with low SNR and a single receiving antenna, lower M and C are needed to attain the same PER. This implies that a wider bandwidth or more OFDM signals must be mapped to more data subcarriers. The meanings of all the symbols in this article are listed in Table 2, along with the corresponding simulation values.

Table 2: Simulation Parameters used in 5GNR under IIoT applications

Payload size	L	1 and 10 (bytes)
Order of Modulation	M	4,16,64,256
Rate of Coding	C	Refer [18]
Number of resource blocks	RB	Refer to [17]
Numerology parameter	µ	0,1,2 in FR1 and 2,3 in FR2
Number of OFDM symbols in a packet	N_{symb}	2,4,7 in DL,>=1 in UL
Number of Receiving antenna	N_{RX}	1 at FR1, 2 at FR2
Packet error rate	PER	$<10^{-6}$
Transmission Power	P_{rx}	20dBm
Path Loss	PL	90,115dB at FR1, 94dB at FR2
OFDM symbol duration including CP (µs)	T_{symb}^{μ}	71.35,35.68,17.84, 8.92 for µ=0.3

4 Results

The ACO optimization problem establishes the lowest bandwidth needed to send a single packet while the time domain's OFDM symbol count fluctuates. We use MATLAB simulations to confirm the PER requirement as given in equation (3c), as the PER depends on the packet bandwidth, modulation, and coding technique. For shifting optimization parameters and payload, we switch the combination of M and C at each site from high order to low. The corresponding needed Wt may be obtained by using equations (3a), (3b), and (3c). The least amount of dependable bandwidth required to transport a single packet is determined through simulation if the parameters chosen satisfy (3c); if not, M and C should be combined in a lower order and the process repeated. For every given parameter, several packets are generated in order to achieve low PER. To characterize omnidirectional transmission with angular spreads, the tapped delay line model and the clustered delay line (CDL) model from the 5G standard [20] are chosen, respectively. In compliance with the 5G standard, we chose a transmission power level of 20 dBm. The pathloss and delay spread values are calculated using the results at 2.25 and 5.4 GHz as there is no industrial channel measurement data available for the 5G NR frequency bands [21]. The steam generation plant, a medium-sized facility with a maximum connection distance of 35 m, exhibits significant multipath fading. The device serving as a BS is positioned above the other devices in relation to the ground. The steam generation plant's maximum pathloss and delay spread are 90 dB and 55 ns, respectively.

An automobile assembly plants with assembly work cells, stacked storage facilities, and machining areas connected by a predetermined maximum connection distance often make up the industrial site. Based on the findings of the channel measurement, the CDL channel's properties are determined [22]. The azimuthal angular dispersion of the arrival and departure is 41 and 80 degrees, respectively. Beamforming is not used in the simulation. For industrial sites with greater route losses and longer communication ranges, beamforming can be used to achieve the right SNR. The Doppler shift at each site is fixed at a speed of 2.5 m/s.

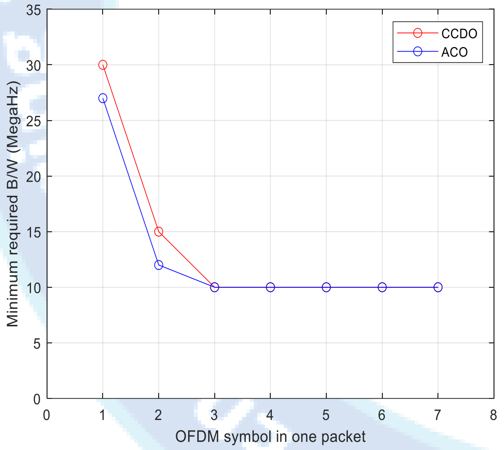

Fig. 2a: The minimum bandwidth Wt, found by equation (4.2) for PER< 10^{-6}. Ten and one hundred bytes are the PHY payload sizes. The parameters of numerology at μ = 0–10 are applied.

Figs. (2a) and (2b) (b) display the minimal weight needed at a certain position in order to get a PER of 10-6. To meet the reliability criterion, the payload in the AA plant is modulated using M = 2 (QPSK) and C = 349/1024. The industrial plants have M = 4 (16QAM) and C = 658/1024 give the necessary reliability performance. The minimal Wt required for each grows with L and decreases with Nsymb, per equation (2a).

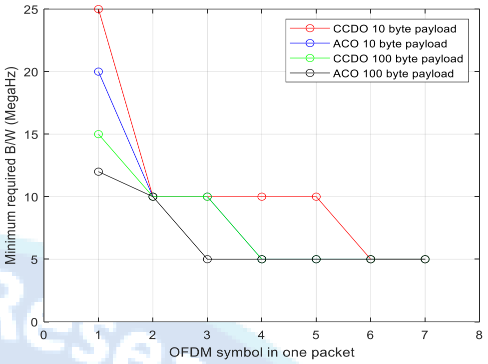

Fig. 2b: Wt found by calculating equation (3) for PER< 10^{-6}. Ten and one hundred bytes are the PHY payload sizes at numerology parameters when μ=2, 3.

Finding the least BWP for each value yields the lower bound of the minimum necessary Wt, which is equal to 5 MHz for values of = 0 and 1, and equal to 10 MHz for values of = 2. The minimum needed Wt rises in line with the SCS while fixing Nsymb μ. Equation (2a) produces a higher minimum necessary weight in Fig. (2b) than in Fig. (2a), since lower values of M and C are required to compensate for increased pathloss and obtain the same PER performance. No Wt value in Fig. 2b can meet the PER criterion for Nsymb 2 with = 1 and Nsymb 4 with = 2 with a 100-byte payload size. The smallest BWPs are associated with a significant proportion of RB that have a payload size of 10 or 100 bytes and a variable Nsymb; this value can meet criterion eq (3a) through (3c).

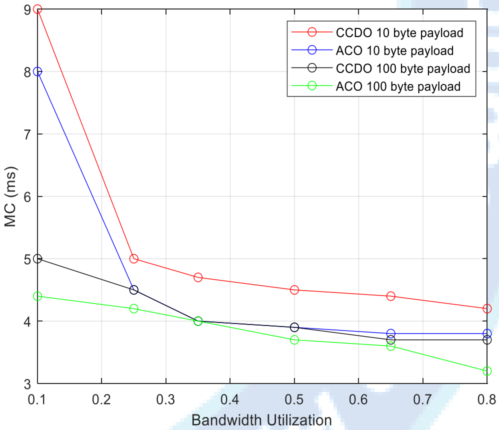

Fig. 3 Minimum packet transmission time with respect to bandwidth utilization.

Figure 3 displays the findings between the bandwidth utilization along the x-axis and the Minimum packet transmission (MC)) in msecs on the y-axis. The experiment is conducted with varying payload quantities of 1 byte and 10 byte in order to compare the transmission under the CCDO and the suggested ACO technique. It has been discovered that, in comparison to CCDO, the minimum packet transmission time for the suggested ACO-based optimization strategy results in lower MC values. In every example, the MC is declining as bandwidth use rises.

Figure 4 displays the relationship between the number of OFDM signals in a data packet along the x-axis and the Minimum packet transmission time (MC) in msecs on the y-axis. It is carried out using several modulation schemes at BPSK, QPSK, and 8PSK with a 1-byte payload in order to compare the transmission under the CCDO and the suggested ACO method. It has been discovered that, for all modulation schemes, the lowest packet transmission time for the suggested ACO-based optimization approach results in lower MC values than CCDO.

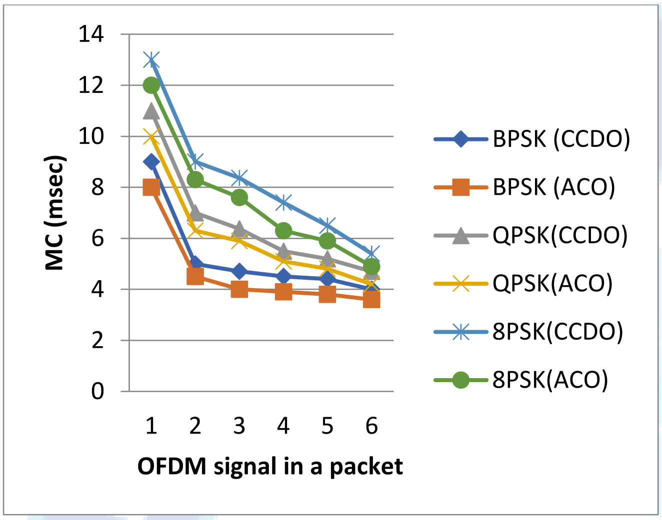

Fig 4: Minimum packet transmission time with respect OFDM signal in a packet for 1 Byte payload.

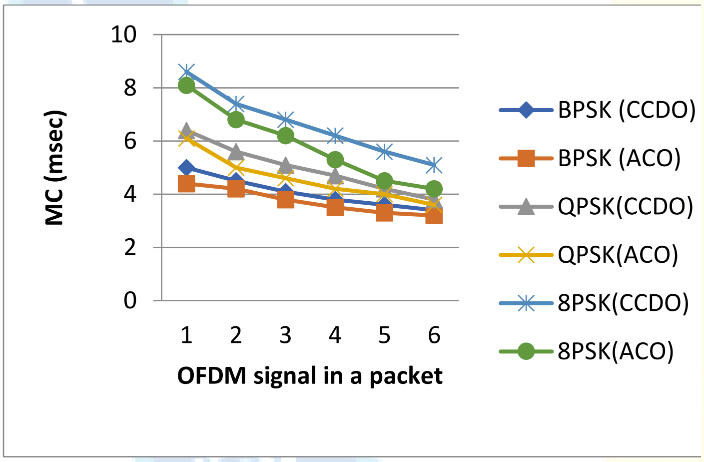

Fig 5: Minimum packet cycle transmission time with respect OFDM signal in a packet for 10 Byte payload.

Figure 5 displays the relationship between the amount of OFDM signals in a data packet along the x-axis and the Minimum packet transmission time (MC) in msecs on the y-axis. It is carried out at

various sorts of modulation schemes at 10 bytes of payload at BPSK, QPSK, and 8PSK to compare the transmission under CCDO and suggested ACO method. It has been discovered that, for all modulation schemes, the suggested ACO-based optimization scheme's minimal packet transmission time results in lower MC values than CCDO.

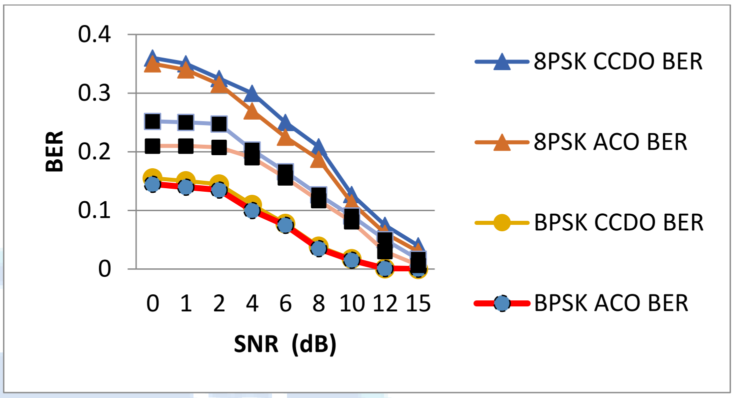

Fig 6: Bit Error with respect SNR in dB

The findings are shown in Figure 6 between the Bit Error Rate (BER) on the y-axis and the SNR (dB) for data packet transmission along the x-axis. The transmission under CCDO is compared to the recommended ACO approach using several modulation schemes, such as BPSK, QPSK, and 8PSK. It is found that the BER for the proposed ACO-based optimization technique provides lower MC values than CCDO for all modulation schemes. Under all conditions, the BER drops as the SNR increases.

5 Conclusion

In industry where high reliability is required because ACO-based OFDM has higher spectrum efficiency than OFDM, it is thought to be superior in 5G. Because subband allocation has the benefit of lowering the size of the FFT and the guards between sub-bands, this technique is promising for short duartion data. The latter feature is also appealing when compared to other optimization, which has a much greater FFT duration. The outcome demonstrates that 5G NR can accomplish a few milliseconds for various sample industrial sites' control mechanisms. In the future, the recommended approach under this method may be used to different noncellular wireless technologies that are now in trial mode with regard to cycle durations. In the future, a checking table may be included to document various channel characteristics, such pathloss and signal angle, as well as the corresponding minimum needed bandwidth, modulation, and coding. To provide a reliable MCT, a network management entity may be set up to maintain this table and use hybrid optimization techniques to calculate the scheduling and transmission parameters. Although they are more accurate, current optimization algorithms have the disadvantage of being quite complicated and taking a long time of convergence. Research has shown that a stronger and more optimal solution may be obtained by merging two distinct weak optimization strategies. In the future, we may concentrate on these topologies in the optimization process to make it faster, easier, and more precise.

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