Semi-Persistent Scheduling Scheme for Low-Latency and High-Reliability Transmissions in Private 5G Networks

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***Index Terms*—Private 5G networks, semi-persistent scheduling, low-latency and high-reliable transmissions, stochastic geometry.**

I. INTRODUCTION

Fifth-generation (5G) networks have proliferated globally and already been widely deployed in public commercial networks. Recently, 5G technologies have been becoming a promising technology of industries and private applications due to their significant benefits, including high capacity and high quality of service (QoS) [1], [2]. Moreover, for safety, security, and privacy, some industrial and private applications, such as transportation, mining, container port, health care, and manufacturing, intend to operate relying on their own private networks rather than public commercial networks [3], [4]. Despite tremendous benefits and promises, private applications may require a high level on flexibility and customization to meet their requirements, which need to be met by redesigning existing 5G technologies [4].

In this paper, we focus on studying the scheduling scheme for private 5G networks, enabling low-latency and high-reliability uplink transmissions. Recently, the governments of German, USA, Japan, and Singapore have granted licensed frequency bands for private use [5]. Accordingly, we consider private 5G networks possessing licensed spectrum without interference from other wireless systems. In traditional scheduling methods, the system will assign wireless resources according to users' data requirements and channel states. If a device has data to transmit, it has to receive the measurement configuration from a base station (BS) first, so that the device can send reference signals to the BS for uplink channel measurements. Meanwhile, the device needs to send scheduling request indicator (SRI) to the BS, requesting wireless resources for uplink transmissions. Based on measured uplink channel states and users' requests, the BS conducts scheduling for all users and informs them of scheduling results through scheduling signaling transmitted on physical downlink control channels [6]. To adapt to the change of wireless environments, scheduling is conducted and updated very frequently. For example, in LTE systems, scheduling could be carried out as frequently as every sub-frame (1 ms) [7]. Traditional scheduling methods relying on a series of the aforementioned complicated system procedures may be inapplicable in private 5G networks because of their special characteristics [4], including: (i) Data to be transmitted may be short messages, such as machine control commands, sensor information, and health care data, and need to be transmitted periodically and frequently; (ii) Some messages are delay-sensitive, and have a pre-defined lifetime, so that they are outdated at the end of their lifetimes; (iii) Numerous users may coexist in private 5G networks. For example, in an industrial environment, a large amount of Industrial Internet-Of-Things (IIoT) devices may need to be supported by private 5G networks; and (iv) For industrial automation, motion control, low latency, high reliability, and determinism are key QoS requirements.

Based on the analysis above, the traditional scheduling may not be capable of supporting private 5G networks due to two main technical issues. First, numerous users with massive frequent short messages will result in huge burden and overhead to the system if the traditional scheduling relying on complicated system procedures is applied. Second, numerous users and massive messages may prolong the time of signal processing and computations in traditional scheduling, causing a long delay and making delay-sensitive messages expired.

In this paper, we redesign the scheduling process for private 5G networks with licensed frequency bands. For low-latency and high-reliability uplink transmissions, a semi-persistent

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scheduling (SPS) scheme is developed to enable “grant-free” and immediate uplink access to private 5G users. SPS has already been introduced to offer low-latency and efficient transmissions. In [8] and [9], a sensing-based SPS was proposed to support vehicle-to-vehicle transmissions, where a channel consists of multiple resource blocks (RBs). In each channel, the first two RBs are used to transmit sidelink control information (SCI), which carries the information of occupied channels and the transmission interval to let other vehicles know the occupancy of channels. Based on the SCI, vehicles select and reserve channels to avoid collisions. In [10], an SPS mechanism was proposed for ultra-reliable low-latency communications in 5G new radio, where a user has a main SPS occasion and an optional SPS occasion in an SPS period. The main SPS occasion is used to transmit data and deliver the information of whether the optional SPS occasion will be used. If the SPS user will not use it, the system can reallocate optional SPS resources to other users. Since the existing work in SPS does not study the reliability improvement of SPS, which is the inherent disadvantage of SPS, we focus on both the technical details design of our proposed SPS scheme and the scheduling algorithm aimed at improving reliability.

In our proposed SPS scheme, instead of re-scheduling SPS channels in each sub-frame (1 ms), we define a minimum scheduling time unit, called an SPS period, which consists of multiple sub-frames. With the developed scheduling scheme, users use the same allocated and reserved wireless resources to conduct uplink transmissions within the SPS period. By this way, if a private 5G device has messages that need to be transmitted, it could immediately access its allocated SPS channels to transmit data without waiting for the scheduling by the BS. As a result, the latency of uplink transmissions can be reduced. Additionally, the system process of both private 5G BSs and users would be more efficient with a low operational complexity, as the complicated system procedures that support frequent and instantaneous resource allocations are not needed.

Apparently, the use of SPS is not effective in terms of reliability, since wireless resource cannot be allocated according to accurate and instantaneous channel states. Under SPS, the most reliable way is to consider the potential worst channel state in the SPS scheduling. However, this will require extra redundant wireless resources, which will be wasted. Additionally, only the limited number of users can be served with SPS due to this under-utilization of wireless resources. Thus, the SPS scheduling should consider both reliability and wireless resource utilization. To achieve this goal, the distance distribution between a BS and a user is considered in evaluating channel states rather than a particular distance, which is derived using the stochastic geometry. Then, the reliability of the proposed SPS is enhanced with two steps. First, modulation and coding schemes (MCSs) are properly selected, taking into account potential channel states and risks in an SPS period rather than only current channel states. Second, using selected MCSs and the data expectation on an SPS channel, a novel SPS optimization algorithm is proposed aiming at reliability improvement, fairness guarantee, and data rate maximization.

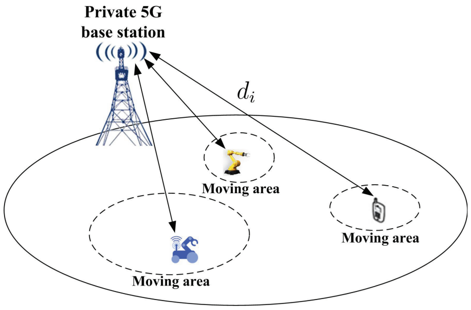

Fig. 1. System model of a private 5G network.

II. SYSTEM MODEL

In this paper, we assume that a private 5G network is deployed in the licensed frequency bands. It consists of a private 5G BS and multiple users as illustrated in Fig. 1. It is also assumed that different types of private 5G users coexist in the network with different types of mobility, such as human users, vehicles, and robots. All users connect to the private 5G BS, conducting uplink data transmissions, while the BS carries out SPS and schedules each user periodically through downlink control channels. It is assumed that there are M SPS channels and U users. Let $\mathbf{U}$ be the set of all users, $\mathbf{U} = \{i | i = 1, 2, \cdots, U\}$. Since SPS channel resources are limited, SPS channel resources may not be able to support all users to be served by a private network. Only partial users will be served as SPS users, which should be properly selected considering both reliability and fairness guarantee. Since private 5G users may be deployed in indoor scenarios with dense devices, such as industrial factories, hospitals, and stations, the indoor hotspot scenario (scenario B3) of the WINNER II channel model is adopted to specify the large-scale fading, which is established based on the measurement of the indoor industrial scenario. Accordingly, the path loss is specified as follows [11]:

$$PL(d_i) = 10^{-(13.7\log_{10}(d_i)+65.3)/10}, \tag{1}$$

where d_i represents the distance between the BS and user i. It is important to note that in our proposed SPS scheme the distance d_i within the SPS period is a random variable due to the mobility of users.

Since it is also likely for private 5G networks to be applied in the indoor environment, where wireless signals may be obstructed and scattered by buildings, equipment, and other devices, Rayleigh fading is adopted to characterize small-scale fading. Accordingly, user i's small-scale fading is notated by h_i. With licensed frequency bands, private 5G networks can exclusively access their wireless channels without interference from other systems. To guarantee reliability and avoid interference, an SPS channel is only allocated to a user. Accordingly, the signal-to-noise ratio (SNR) is used to characterize channel states, which is given by $\mathrm{SNR}_i \overset{\triangle}{=} \rho_i PL(d_i)|h_i|^2$, where $\rho_i \overset{\triangle}{=} \frac{P_i}{BN_0}$ with P_i denoting the transmit power of user i. The power gain of the small-scale fading is denoted by $|h_i|^2$. In addition, B and N_0 respectively denote the bandwidth of an SPS channel and noise spectral density.

III. PROPOSED SEMI-PERSISTENT SCHEDULING SCHEME

To enhance scheduling efficiency, reduce transmission latency, and mitigate system complexity, an SPS scheme is proposed with a new frame structure. Fig. 2 shows the frame structure of the proposed SPS scheme, where the time domain is divided into SPS periods with the identical time length, while each SPS period consists of multiple sub-frames. Each sub-frame is classified into one of the three sub-frames: (i) a data sub-frame; (ii) an SPS scheduling signaling sub-frame; and (iii) a moving area report sub-frame. Data sub-frames are merely used to transmit data. The SPS scheduling signaling sub-frame is a downlink sub-frame and the first sub-frame in an SPS period, which is used to send SPS control signaling. The moving area report sub-frame is the last sub-frame of each SPS period, which carries position information sent to the BS. The position information of a user is utilized to evaluate its moving area in the next SPS period. As shown in Fig. 3, let (x_0, y_0), v, and T be a user's position provided by its reported position information, the user's maximum velocity, and the time length of the SPS period, respectively. Since the movement of a user is unpredictable within the SPS period, the moving area of a user is defined as a circle centered around (x_0, y_0) with a radius of $v \times T$, without loss of generality. Accordingly, the moving area involves all possible positions of the user in the next SPS period. Apart from position information, users can also report and update their data rate requirements through the moving area report sub-frame if their requirements have changed. For freshness, the moving area report sub-frame is located at the last sub-frame of each SPS period to provide the latest position information. It is noticeable that obtaining accurate position information relies on additional modules, such as global position system (GPS). Unfortunately, GPS signals are not always available in the considered local areas, and so alternative localization technologies [12], [13] may be needed to provide position information.

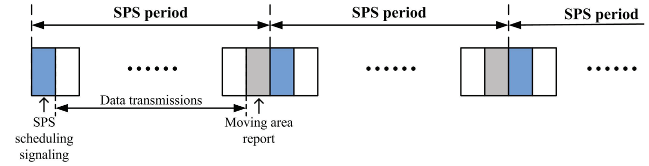

Fig. 2. Frame structure of the proposed semi-persistent scheduling.

The process of the proposed SPS scheme is described as follows. All users need to report their position information to the BS in the last sub-frame of the current SPS period. After receiving users' position information, the BS will conduct signal processing and SPS to obtain channel scheduling results. Afterwards, the BS informs each user of the SPS results through the SPS scheduling signaling sub-frame, which is the first sub-frame of the next SPS period. According to the SPS results, users perform uplink transmissions on the allocated SPS channels in the next SPS period, including all the data sub-frames and the moving area report sub-frame. Thus, the proposed SPS scheme makes SPS users immediately access their allocated/reserved SPS channels to send data without requesting wireless resources and waiting for being scheduled. This "grant-free" nature makes uplink transmissions more efficient with a low system complexity and a low latency.

IV. DISTANCE DISTRIBUTION AND COVERAGE PROBABILITY

In the SPS period, the movement of a user is unknown within its moving area. The distance between BS and the user is a random variable, so that its distribution is derived via stochastic geometry [14], [15]. As illustrated in Fig. 3, it is assumed that the BS is located at origin $(0, 0)$ with the height of l, while the center of the user's moving area and an arbitrary position within the SPS period are (x_0, y_0) and (x_1, y_1), respectively. (x_0, y_0) is fixed and known, which is provided by the moving area report sub-frame. In contrast, (x_1, y_1) is unknown and randomly selected. Let $\mathbf{x}_0 = (x_0, y_0)$, $\mathbf{x_1} = (x_1 - x_0, y_1 - y_0)$, and $\mathbf{y} = (x_1, y_1)$ denote the vectors from the BS to the moving area center, from the moving area center to the user, and from the BS to the user, respectively. The distance between the BS and the user is given by $\bar{d} = \sqrt{x_1^2 + y_1^2}$. Without loss of generality, we assume that a user is uniformly distributed in its moving area with the radius of r. Then, the conditional probability density function (PDF) of $\bar{d} = \sqrt{x_1^2 + y_1^2}$ conditioned on $\|\mathbf{x}_0\|$ is computed as [16]:

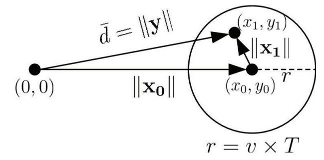

Fig. 3. The model of the distance between a BS and a user.

$$f_{\bar{D}}(\bar{d} | \|\mathbf{x_0}\|) = \frac{2\bar{d}}{\pi r^2}\Big(\frac{\pi}{2} - \arcsin\frac{\bar{d}^2 + \|\mathbf{x}_0\|^2 - r^2}{2\|\mathbf{x}_0\|\bar{d}}\Big), \text{ for } \min(0, \|\mathbf{x}_0\| - r) \leq \bar{d} \leq \|\mathbf{x}_0\| + r. \quad (2)$$

With the BS height of l, the distance between the BS and user is $d = \sqrt{\bar{d}^2 + l^2}$. Then, according to (2), the PDF of d is computed as follows:

$$\begin{aligned} f_D(d | \|\mathbf{x}_0\|) &= f_{\bar{D}}(\bar{d} \|\mathbf{x}_0\|) \left|\frac{\partial \bar{d}}{\partial d}\right|_{\bar{d} = \sqrt{d^2 - l^2}} \\ &= \frac{2d}{\pi r^2}\Big(\frac{\pi}{2} - \arcsin\frac{d^2 - l^2 + \|\mathbf{x}_0\|^2 - r^2}{2\|\mathbf{x}_0\|\sqrt{d^2 - l^2}}\Big), \\ &\quad \text{for } \Delta_A \leq d \leq \Delta_B, \end{aligned} \quad (3)$$

where $\Delta_A \overset{\triangle}{=} \min(\sqrt{(\|\mathbf{x}_0\| - r)^2 + l^2}, l)$ and $\Delta_B \overset{\triangle}{=} \sqrt{(\|\mathbf{x}_0\| + r)^2 + l^2}$. According to [14], the coverage probability is defined as the probability that the SNR of received signals exceeds a threshold Γ for successful demodulation and decoding. The value of Γ is pre-defined according to [17]. Given the distance distribution, the coverage probability is obtained as follows [14]:

$$\begin{aligned}\Pr(\rho PL(d)|h|^2 \geq \Gamma) &= \int \Pr(\rho PL(d)|h|^2 \geq \Gamma|D) f_D(d)\mathrm{d}d \\ &= \mathbb{E}_D\big[\Pr(|h|^2 \geq \Gamma/\rho PL(d)|D)\big] \\ &\overset{(a)}{=} \int \exp(-\frac{\Gamma}{\rho PL(d)}) f_D(d|\|\mathbf{x}_0\|)\mathrm{d}d, \quad (4)\end{aligned}$$

where $\rho \overset{\triangle}{=} \frac{P}{BN_0}$. In addition, $\Pr(\cdot)$ and $\mathbb{E}[\cdot]$ denote probability and expectation, respectively. In (4), (a) follows the fact that the power gain of the Rayleigh fading channel obeys the exponential distribution.

V. SPS ALGORITHM FOR RELIABILITY ENHANCEMENT

The designed SPS scheme may encounter a low-reliability issue, as within the SPS period the system cannot re-schedule wireless resources to adapt to any change of the wireless environment. For reliability enhancement, a novel SPS algorithm is proposed in this section with two main components, MCS selection and SPS optimization.

A. MCS selection

The MCS used by a user to conduct wireless transmissions is determined by its channel states. However, with the proposed SPS scheme, an SPS user cannot adjust and reselect MCS based on instantaneous channel states, while within an SPS period the SPS user has to transmit using the same predefined MCS. Therefore, the MCS selection needs to consider and cover all possible channel states in the SPS period to preserve its high probability of successful demodulation and decoding.

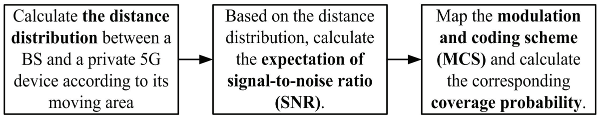

Fig. 4. The selection of modulation and code schemes.

Fig. 4 shows the process of the MCS selection designed in this paper. First, according to user i's moving area, the distribution of the distance between the BS and user i is computed using stochastic geometry, which is derived in Section IV. Then, given the distance distribution, the expected SNR of user i in the SPS period is evaluated, which will be used to determine user i's MCS. The expected SNR of user i is computed as follows:

$$\mathbb{E}_{D_i}[\mathrm{SNR}_i] = \int \rho_i PL(d_i)|h_i|^2 f_{D_i}(d_i)\mathrm{d}d_i. \quad (5)$$

Afterwards, the mapping between user i's expected SNR and MCS is carried out according to [17], where given a SNR value, the corresponding MCS is chosen. The selected MCS would be the one that could provide the highest data rate among MCSs that guarantees successful demodulation and decoding under the SNR. Following the LTE specification, it is assumed that the SPS channel is a physical resource block (PRB) with 180 kHz bandwidth and 168 symbols [7].

B. SPS optimization

Given the selected MCS of user i, the SNR threshold for successful demodulation and decoding, Γ_i, can be determined. Moreover, the amount of data carried by the SPS channel, R_i, is fixed, which is dominated by user i's MCS. An optimization problem aiming at reliability enhancement and fairness guarantee, is formulated as follows:

$$\begin{aligned}&\max \sum\nolimits_{i\in\mathbf{U}} M_i R_i \Pr(\rho_i PL(d_i)|h_i|^2 \geq \Gamma_i) \text{ such that} \\ &(i) M_i R_i \Pr(\rho_i PL(d_i)|h_i|^2 \geq \Gamma_i) \leq \hat{R}_i^{\mathrm{tot}}, \text{ for } \forall i \in \mathbf{U} \text{ and} \\ &\qquad (ii) \sum\nolimits_{i\in\mathbf{U}} M_i \leq M, \qquad (6)\end{aligned}$$

where M_i is the number of SPS channels allocated to user i, which is the variable of the optimization problem (6). In the constraints, $\hat{R}_i^{\mathrm{tot}}$ and M represent the data rate constraint of user i and the total number of SPS channels, respectively.

The objective function of (6) is to maximize the sum of all users' transmitted data expectations, where the expectation of data transmitted on the SPS channel, $R_i \Pr(\rho_i PL(d_i)|h_i|^2 \geq \Gamma_i)$, is considered instead of instantaneous achievable data rate or instantaneous channel states that are widely adopted in traditional scheduling schemes. The expectation of transmitted data could reflect the potential channel states in the SPS period, which is determined by the selected MCS and the coverage probability with distance distribution described in (4). The use of the transmitted data expectation enables the private 5G network to assign adequate wireless resources to guarantee that users' requirements can be met even under the worst wireless environments. The first constraint is used to restrict the number of channels assigned to a user. In this way, the SPS channel resources assigned to a user are just sufficient to meet its data rate requirements and guarantee its reliability, rather than redundant resources allocated to pursue global maximization. As a result, given limited SPS channel resources restricted by the second constraint, as many users as possible could be served with low-latency SPS transmissions with preferable reliability. It is noticeable that $\hat{R}_i^{\mathrm{tot}}$ is not exactly equal to the data rate requirement of user i, R_i^{tot}, where R_i^{tot} is the amount of data required to be transmitted in a sub-frame. This is because the data rate requirement R_i^{tot} utilized as an upper bound on the first constraint may cause that SPS channel resources actually allocated to user i cannot meet its requirement. Thus, $\hat{R}_i^{\mathrm{tot}}$ should be larger than R_i^{tot} in an appropriate level, avoiding wasting resources. Here, $\hat{R}_i^{\mathrm{tot}}$ is defined as the minimum multiple of user i's data expectation that is larger than R_i^{tot}, $\hat{R}_i^{\mathrm{tot}} = \min\{nE_i | nE_i \geq R_i^{\mathrm{tot}}\}$, where n is a positive integer, and E_i is the data expectation on the SPS channel, that is, $E_i = R_i \Pr(\rho_i PL(d_i)|h_i|^2 \geq \Gamma_i)$.

With the optimization problem (6), the private 5G system intends to assign SPS channels to users with the high expectation of transmitted data with two reasons. First, assigning the SPS channel to a user with the high data expectation is beneficial to global maximization. Second, for a user with a higher data expectation, under the same data requirements, fewer channels assigned to this user could meet its requirements, so that more channel resources can be saved to serve other users, making more users served with SPS. Clearly, through the optimization problem (6), a good tradeoff could be achieved between data rate, reliability, and fairness.

VI. SIMULATION RESULTS AND ANALYSIS

Through simulation studies, the effectiveness and superiority of our proposed SPS scheme is demonstrated. To verify the effectiveness of the proposed MCS selection method and using the data expectation of the SPS channel in the SPS optimization, the performance of the proposed scheme will be compared with using the instantaneous achievable data rate (ADR), defined by $B\log_2(1+\mathrm{SNR}_{i,\mathrm{ins}})$ in SPS. Moreover, the actual transmitted data, which is determined by the MCS selected based on instantaneous SNR, $\mathrm{SNR}_{i,\mathrm{ins}}$, will also be adopted as a compared method, also referred to as instantaneous MCS. Note that the data expectation, instantaneous ADR, and instantaneous MCS will be measured and used in SPS at the beginning of an SPS period. Besides, we also explore if the low-complexity greedy algorithm is a proper method to solve the optimization problem (6) by comparing the simulation results of the greedy algorithm with those of solving optimization problem with the optimization toolbox of MATLAB.

In the simulation, according to [11] and [18], SPS channel bandwidth B, noise power spectral density N_0, and the deviation of log-normal shadow fading are set to be 180 kHz, -174 dBm/Hz, and 3.1 dB, respectively. Moreover, the transmit power of a private 5G user on the SPS channel, P, is assumed to be a relatively small value, 20 dBm/10 MHz, for energy saving and long lifetime. The maximum velocity of users v is assumed to be 10 m/s. Considering the fact that different types of private 5G users may have different data rate requirements, R_i^{tot} of user i is decided by randomly selecting from 1000, 3000, and 5000 bits per sub-frame. All simulation results show the average values of 100 SPS periods. In different SPS periods, the reported positions (x_0, y_0) and the corresponding moving areas of all users would be re-generated and reshuffled in an area centered around the BS with radius of 400 m. Within the SPS period, users are moving in the same moving area, while in different sub-frames users are located at different positions.

Fig. 5 plots the satisfied SPS user rate versus the number of users, which is the percentage of satisfied users in all SPS users with non-zero M_i, under 100 SPS channels and the SPS period time length of 20 s (20000 sub-frames). Whether a user is an SPS user is determined by the SPS scheduling conducted based on the optimization problem (6). If $M_i \neq 0$, user i becomes an SPS user, otherwise it becomes a non-SPS user. Moreover, an SPS user is a satisfied one only if two conditions are satisfied: (i) The SPS channels allocated to this user can meet its data rate requirements; and (ii) In a sub-frame, the user's instantaneous channel state can support its pre-defined MCS for successful modulation and coding. When the instantaneous ADR is used, SPS will result in an extremely low satisfied SPS user rate. Since the instantaneous ADR is a theoretical capacity on a channel, it is greatly larger than the transmitted data in reality. With the instantaneous ADR, users may be allocated with insufficient channels, which cannot meet their data rate requirements. Obviously, our proposed SPS scheme can achieve better performance on the satisfied SPS user rate compared to others and can always preserve the performance on the high level by jointly considering potential channel states and risks.

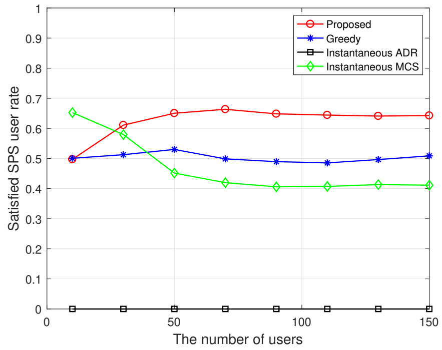

Fig. 5. The satisfied SPS user rate versus the number of users.

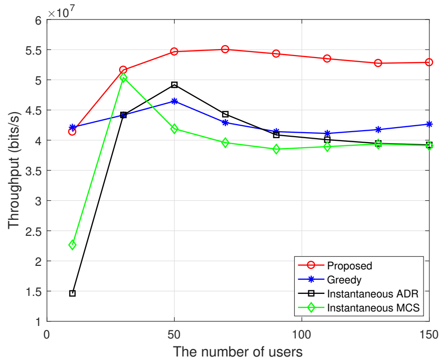

Fig. 6. Throughput versus the number of users.

Fig. 6 presents the total successfully transmitted data per second, also referred to as throughput as a function of the number of users. With our designed SPS optimization, the system will only allocate adequate SPS channel resources to meet users' requirements and guarantee their reliability, rather than redundant resources allocated for global maximization. Thus, when the number of users is small, the throughput increases proportionally to the number of users. However, with more users in the network, the ADR scheduling with inaccurate estimations of data carried by a channel will inappropriately include too many users to be served with SPS. Thus, it is hard to guarantee reliability and meet requirements. Consequently, the throughput will decline when the number of users becomes large. Furthermore, our proposed SPS scheme achieves the greatest throughput and can remain it irrespective of the number of users, indicating that its high reliability could lead to high throughput. In addition, this figure shows that the greedy algorithm can bring in a preferable performance, but it cannot achieve the optimal performance.

The satisfied SPS user rate and the throughput versus the

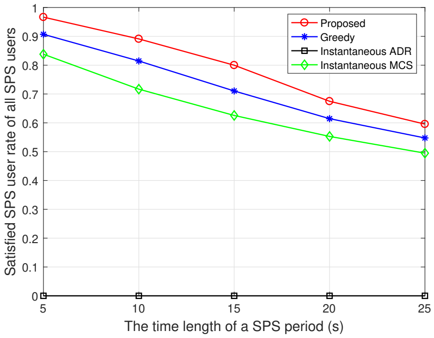

Fig. 7. Throughput versus the time length of an SPS period.

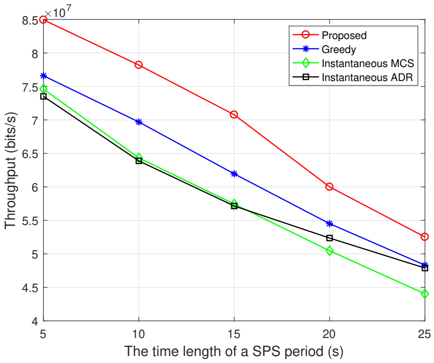

Fig. 8. Throughput versus the time length of an SPS period.

time length of an SPS period are shown in Fig. 7 and Fig. 8, respectively. According to the definition of the moving area in Fig. 3, a larger SPS period time length will bring in larger moving areas with more potential channel states and risks as well as stronger uncertainty and randomness, so that it becomes challenging to guarantee a desirable reliability. From Fig. 7, the satisfied SPS user rate will decrease with the increase of the SPS period. Due to enhanced performance on reliability, the proposed scheme always has better performance on the satisfied SPS user rate than others. By comprehensively considering potential channel states and risks in the SPS period, the proposed SPS scheme can properly select MCS for users and assign adequate SPS channel resources to guarantee successful demodulation and decoding of transmitted data and meet users' data rate requirements. As shown in Fig. 8, the proposed SPS scheme can achieve greater throughput compared to others, since enhanced throughput benefits from greater reliability.

VII. CONCLUSION

In this paper, a semi-persistent scheduling scheme has been developed for private 5G networks. It has been designed to schedule SPS users at the beginning of an SPS period according to their moving area reported through the last sub-frame of the previous SPS period. Within the SPS period, SPS users will keep using the scheduled SPS channel resources to carry out uplink transmissions. In this way, "grant-free" and immediate uplink access can be achieved without requesting resources to BSs and waiting for scheduling. In addition, the developed scheme has been capable of significantly reducing the latency of uplink transmissions as well as mitigating system complexity and overhead. However, low reliability may arise with the proposed scheme, as channel resources cannot be adaptively scheduled according to the change of wireless environments in the SPS period. To conquer this disadvantage, an SPS algorithm has been proposed to enhance reliability, including MCS selection and SPS optimization. Jointly taking into account potential channel states and risks within the SPS period, the SNR expectation based on the distance distribution of the SPS period has been derived to determine the best MCS. Given selected MCSs and the coverage probability derived with the distance distribution, an optimization problem has been formulated in order to maximize global date rate, meanwhile enhance reliability and guarantee fairness. Simulation results have verified that this optimization makes the developed SPS scheme achieve better performance in reliability and throughput compared with the existing schemes.

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