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An Accurate Model of the 3GPP NR Access Point Service Process

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The service process of sessions in 3GPP New Radio (NR) wireless access systems operating in millimeter wave frequency band is heavily affected by the dynamic blockage of propagation paths between user equipment (UE) and access point (AP). Although the ability of UEs' transievers to operate over reflected propagation path components partially compensates for this phenomenon, it simultaneously leads to the dynamic fluctuations in the amount of resources requested during the session lifetime to support the required bitrate. In our study, we formulate an accurate model of the 3GPP NR AP service process by taking into account time-varying changes in the amount of requested resources caused by dynamic blockage of propagation paths. The derived metrics of interest includes new and ongoing session drop probabilities as well as the system resource utilization. The presented numerical results indicate that the presence of blockage events decreases the probability of session drops upon arrival at the expense of increasing blocking probability during the service process. However, it does not drastically affect the system resource utilization.

Key words and phrases: 3GPP New Radio (NR), signal-to-interference ratio, mmWave.

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1. Introduction

In December 2017 3GPP has rectified the Phase 1 LTE-anchored New Radio (NR) access technology. As the 3GPP efforts will now continue towards stand alone NR technology the emphasis of the research community is shifting towards the efficient use of the newly standardized system.

Performance of the mmWave deployments has been recently assessed using the tools of stochastic geometry. Applying the Campbell theorem for functionals over point processes, the moments of aggregate interference in THz and mmWave systems in presence of molecular absorption, human-body blockage, and directional transmit and receive antennas have been derived in [1]. Using the Taylor expansion approximation, the authors then extended their analysis to the moments of signal-to-interference ratio (SIR) in [2]. Particularly, the authors in [3] obtained the probability density function (pdf) of SIR for mmWave systems operating at 28 GHz. The pdfs of interference and SIR in the absence of blockage have been reported in [4]. The SIR distribution is further contributed by [5], where the authors introduced a simple model of atmospheric absorption that assumes a constant attenuation coefficient as well as disregards the effect of blockage. An upper bound on mmWave system capacity in presence of dynamic blockage has been obtained in [6].

The stochastic geometry approach allows to characterize wireless specifics of mmWave communications leaving the question of traffic dynamics in mmWave access networks unanswered. Acknowledging this problem, studies addressing both stochastic components started to appear recently, see, e.g., [7–9]. However, most of these models take simplified assumptions about propagation phenomenon and user equipment (UE) operation assuming that blockage of the line-of-sight path always leads to outage conditions with the currently serving AP.

In this paper, we use the tools of queuing theory to develop an accurate model of the session service process at a 3GPP NR access point (AP). To capture random locations of UE in the service area, the resource requirements are assumed to be random variable. Futhermore, to account for blockage of propagation paths between AP and UE we assume that there is external process of blockage. The target metrics of interest are new and ongoing sessions drop probabilities as well as the system resource utilization.

2. System Model

We consider a single 3GPP NR AP. The amount of resources available at AP is B Hz. Consider a multiserver queuing system with N servers, where arriving sessions require a server and random amount of resources of total volume M. The session arrival process is homogenous Poisson with intensity λ. Each session, upon arrival, requeres radnom amount of resources from the system, R, with cumulative distribution function (CDF) $F_R(x)$. The random nature of resource requests stems from random locations of UE in the AP service zone. Given a certain session rate, the set of modulation and coding schemes (MCS) for 3GPP NR available in 3GPP Relese 15, 3GPP multipath propagation model, and distribution of users in the AP service zone CDF $F_R(x)$ can be found using conventional methods of stochastic geometry [7, 8].

We use the standardized 3GPP stochastic multipath propagation model specified in [10] that assumes that the received power at the UE consists of power coming from a number of rays, including LoS path and several reflected components. At any given instant of time UE is assocuiated with the ray having the highest power. Furthermore, rays are assumed to be blocked by a crowd moving around active UEs. Using the results of [11, 12] one may approximatethe blockage process of rays using Poisson process with intensity μ. Resource requirements of sessions are independent identically distributed random variables, independent of arrival and serving processes, which are determined by probability distribution $\{p_m\}, m \geq 0$.

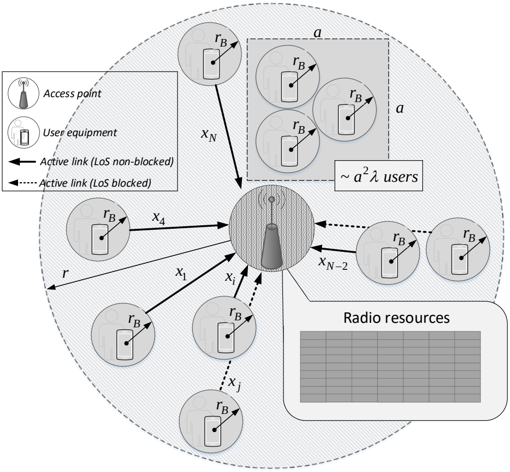

Figure 1. The considered street 3GPP deployment with connectivity operation.

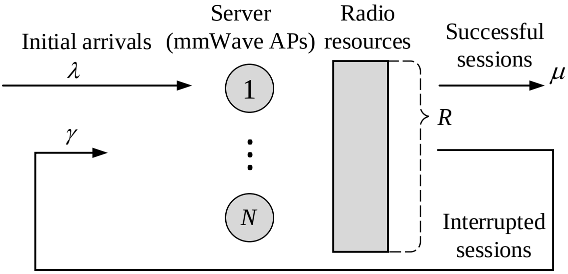

Figure 2. An illustration of the proposed queuing network model.

According to the abovementioned discussion each active session in the system is associated with a homogeneous Poisson process of events with intensity μ.[1] Upon each event the active session changes its resource requirements by drawing them from the CDF $F_R(x)$. If the new resource requirements is smaller, the session continues service at AP. alternatively, if the new resource requirements are higher the session might be dropped if there is insufficient amount of free resources at the AP current. Thus, in the considered system, a session can be dropped upon arrival or during the service process. We are interested in drop probabilities and new and already accepted sessions as well as in system resource utilization.

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[1] In what follows, these events are referred to as "signals".

3. The Queuing Framework

For the analysis of the described queuing system we use the simplified approach, which is common for the queues with random resource requirements. Particularly, instead of keeping track of the amount of resources occupied by each session we track only total amount of resources occupied by all the sessions in the system. While this approach allows to significantly reduce the complexity of the analysis, in the simplified system we do not know the exact number of resources that should be released at the departure time instant of a session or at the arrival time instant of a signal. To alleviate this shortcoming and decide upon the amount ot resources released we use the Bayes law. Particularly, if n sessions in the system occupy m resources, then the probability that i resources are released on the departure time instant is $p_i p_{m-i}^{(n-1)}/p_m^{(n)}$, where $p_m^{(n)}$ is the probability that n sessions occupy m resources. The sought probability is estimated as in (1)

$$p_m^{(n)} = \sum_{i=0}^{m} p_i p_{(m-i)}^{n-1}, n \geq 2. \tag{1}$$

where $p_m^{(1)} = p_m$, $m \geq 0$.

Resource reallocation at the arrival time instant of a signal is performed similarly, i.e., if n sessions in the system occupy m resources, then the probability that i resources are released upon signal arrival is $p_i p_{m-i}^{(n-1)}/p_m^{(n)}$. Thus, after arrival of a signal n sessions occupy k resources with probability $[p_i p_{m-i}^{(n-1)}/p_m^{(n)}]p_{k-m+i}$, $k \leq M$ and with probability $[p_i p_{m-i}^{(n-1)}/p_m^{(n)}](1-\sum_{k=0}^{M-m+i} p_k)$ new resource requirements of the session cannot be fulfilled and it is lost.

Behavior of the system can be described by the stochastic process $X(t) = (\xi(t), \delta(t))$, where $\xi(t)$ denotes number of sessions in the system and $\delta(t)$ is the total amount of occupied resources. The set of states is provided in (2)

$$S = \bigcup_{0 \leq n \leq N} S_n,\ S_n = \left\{(n,m) : 0 \leq m \leq M, p_m^{(n)} > 0\right\}. \tag{2}$$

Arrange the states in S_n in increasing order of the amount of the occupied resource and denote $I(n,m)$ the sequence number of the state (n,m). The stationary probabilities (3) of $X(t)$ are written as

$$q_n(m) = \lim_{t \to \infty} P\left\{\xi(t) = n, \delta(t) = m\right\}, (n,m) \in S_n, \tag{3}$$

The system of equilibrium equations takes the form as in (4)

$$\left(\lambda \sum_{m=0}^{M} p_m\right) q_0(0) = \mu \sum_{m:(1,m)\in S_1} q_1(m) + \gamma \sum_{m:(1,m)\in S_1 q_1(m)} \left(1 - \sum_{i=0}^{M} p_i\right), \tag{4}$$

$$\left(\lambda \sum_{j=0}^{M-j} p_j + n\mu + n\gamma\right) q_n(m) = \lambda \sum_{j:(n-1,m-j)\in S_{n-1}} q_{n-1}(m-j)p_j +$$

$$+ (n+1)\mu \sum_{j:(n+1,m+j)\in S_{n+1}} q_{n+1}(m+j) \frac{p_j p_m^{(n)}}{p_{m+j}^{(n+1)}} +$$

$$+ n\gamma \sum_{j:(n,j)\in S_n} q_n(j) \sum_{i=0}^{min(j,m)} \frac{p_{j-i}p_i^{(n-1)}}{p_j^{(n)}} p_{m-i}+$$

$$+ (n+1)\gamma \sum_{j:(n+1,m+j)\in S_{n+1}} q_{n+1}(m+j) \frac{p_j p_m^{(n)}}{p_{m+j}^{(n+1)}} \cdot \left(1 - \sum_{j=0}^{M-m} p_j\right),$$

$$(n,m)\in S_n, 1\le n\le N-1,$$

$$(N\mu + N\gamma)\, q_N(m) = \lambda \sum_{j:(N-1,m-j)\in S_{N-1}} q_{N-1}(m-j)p_j+$$

$$+N\gamma \sum_{j:(N,j)\in S_N} q_N(j) \sum_{i=0}^{min(j,m)} \frac{p_{j-i}p_i^{(N-1)}}{p_j^{(N)}} p_{m-i}, \quad (N,m)\in S_N.$$

The system of equations (4) - (5) is complemented with the normalization conditions and then solved numerically. Since all state transitions take place between either states from one substate S_n or states from adjacent substates S_n and S_{n-1}, the generator matrix of $X(t)$ can be represented in block-tridiagonal form simplifying the solution.

Using the stationary probabilities, one can evaluate the main performance measures of the system: the average number of occupied resources b in (5), session blocking probability π_d (the probability that a session is lost upon arrival) in (6) and session blocking probability during the service time, π_t (the probability that a session is dropped upon signal arrival) in (7):

$$b = \sum_{(n,m)\in S} m q_n(m), \tag{5}$$

$$\pi_d = 1 - \sum_{(n,m)\in S, n<N} q_n(m) \sum_{j=0}^{M-m} p_j, \tag{6}$$

$$\pi_t = \sum_{(n,m)\in S} q_n(m) \sum_{j=0}^{m} \frac{p_j p_{m-j}^{(n-1)}}{p_m^{(n)}} \left(1 - \sum_{i=0}^{M-m+j} p_i\right). \tag{7}$$

We specifically note that the ongoing session drop probability is interpreted as the fraction of signals that lead to the drop of ongoing session.

4. Numerical Results

In this section we provide sample illustrative results. The default system parameters used in what follows are provided in Table 1 below.

The response of the 3GPP NR system service process to input system parameters is illustrated in Figs. 3-6. Analyzing the behavior of the blocking probabilities upon arrival and during the service time as a function of the session arrival intensity one may observe that over the considered interval both curves are characterized by exponential behavior. Furthermore for the chosen value of system parameters the blocking probability upon session arrival is much higher than the blocking probability of session during the service time. To reveal the detailed behavior of these two metrics consider blocking probabilities upon arrival and during the session time as a function of signal intensity illustrated in Fig. 4. As one may observe, the increase in the signals intensity leads to the decrease in

Table 1

The default system parameters.

Parameter	Value
Number of resource blocks per timeframe	100
Number of servers available	100
Sessions request distribution	geometric
Mean session request size (RBs)	2
Sessions arrival intensity	1, 1.1,...,2
Session service intensity	0.05

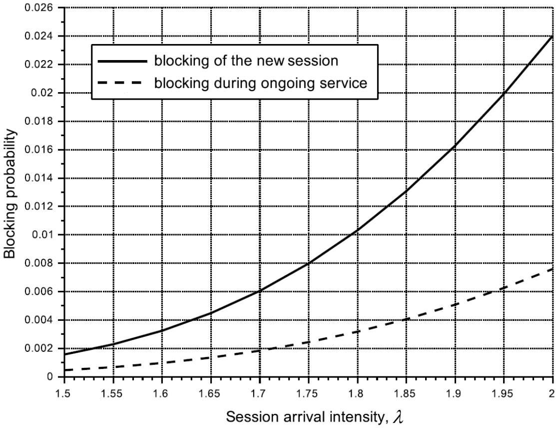

Figure 3. Blocking probability as a function of the session arrival intensity.

the blocking probability of ongoing sessions. The probability that a session is blocked upon arrival decreases as well. The underlying reason for this behavior is that the increase in the signals intensity results in more sessions dropped during the service process due to insufficient amount of resources thus leaving more resources "on average" for new session arrivals. In extreme case when the signals intensities is very high, almost all the sessions are admitted in the system and then eventually dropped during the service process. Alternatively letting the signals intensity approaching zero no losses during the service time are experienced.

Fig. 5 shows the system resource utilization as a function of the signals intensity. As one may observe, for rather wide range of signals intensity the resource utilization remains almost the same. In spite of this behavior, more resources are wasted as signal intensity increases as more sessions leave the system prior to service completions. Thus, aside from classic systems, where system utilization is one of the critical performance indicators for systems provided in prospective 5G systems one has to consider more advanced metrics that quantify not only resource utilization but a fraction of resources wasted due to partial service.

Finally, Fig. 6 shows the new and ongoing session drop probability as a function of mean session size. Recall that keeping the session arrival rate constant while increasing

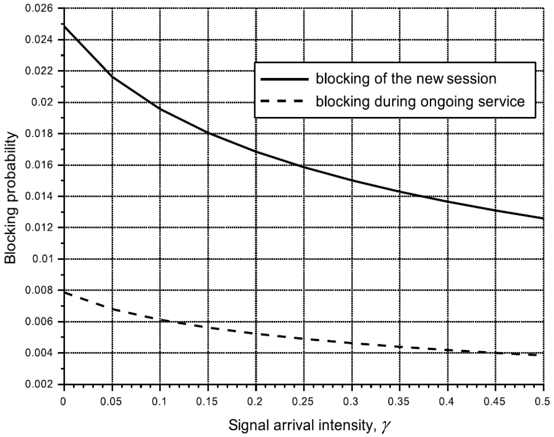

Figure 4. Blocking probability as a function of the signal intensity.

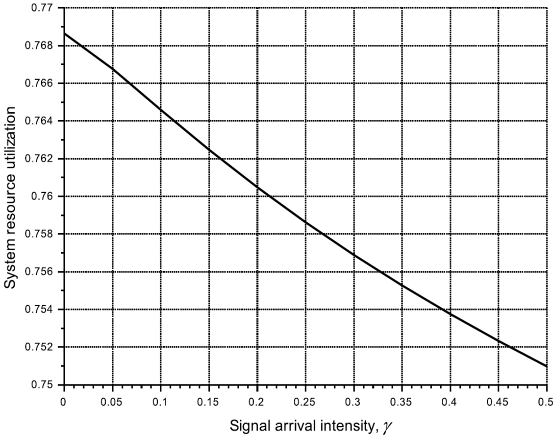

Figure 5. System resource utilization as a function of the signal intensity.

the mean session size we increase the offered traffic load to the size. Thus, expectedly, both probabilities are characterized by the increasing behavior. Similarly to previous illustrations the new session loss probability is higher than the ongoing session drop probability.

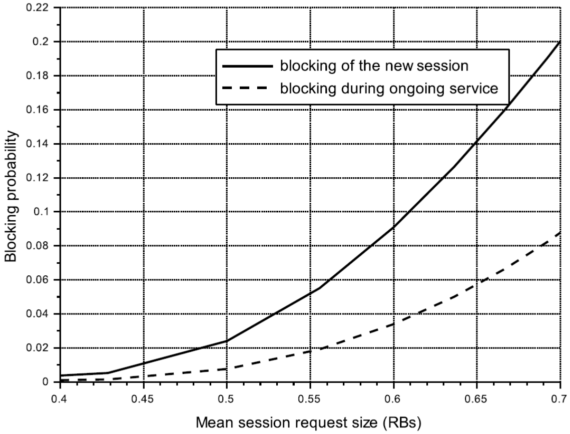

Figure 6. Blocking probability as a function of the mean session request size.

5. Conclusions

In this paper we have developed an accurate model for the 3GPP NR system service process. The proposed models not only accounts for inherently variable session resource requirements induced by random rate requests and random location of users but captures the blockage of propagation path between UEs and AP. The latter is modeled by introducing an external process of events causing resource re-allocations for sessions already accepted to the system.

The developed model allows for systematic analysis of 3GPP NR AP service process in various deployments. The sample numerical results have shown that the presence of external process of signals modeling the blockage process decreases the probability of session drops upon arrival at the expense of increasing blocking probability during the service process. At the same time, it does not drastically affect the system resource utilization.

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References

1. V. Petrov, M. Komarov, D. Moltchanov, J. M. Jornet, Y. Koucheryavy, Interference analysis of ehf/thf communications systems with blocking and directional antennas, in: Global Communications Conference (GLOBECOM), IEEE, 2016, pp. 1–7 (2016).
2. V. Petrov, M. Komarov, D. Moltchanov, J. M. Jornet, Y. Koucheryavy, Interference and sinr in millimeter wave and terahertz communication systems with blocking and directional antennas, IEEE Transactions on Wireless Communications 16 (3) (2017) 1791–1808 (March 2017).

3. K. Venugopal, R. Heath, Millimeter wave networked wearables in dense indoor environments, IEEE Access 4 (2016) 1205–1221 (2016).
4. M. Di Renzo, Stochastic geometry modeling and analysis of multi-tier millimeter wave cellular networks, IEEE Transactions on Wireless Communications 14 (9) (2015) 5038–5057 (2015).
5. S. Singh, M. N. Kulkarni, A. Ghosh, J. G. Andrews, Tractable model for rate in self-backhauled millimeter wave cellular networks, IEEE Journal on Selected Areas in Communications 33 (10) (2015) 2196–2211 (2015).
6. D. Moltchanov, A. Ometov, S. Andreev, Y. Koucheryavy, Upper bound on capacity of 5g mmwave cellular with multi-connectivity capabilities, Electronics Letters 54 (11) (2018) 724–726 (2018).
7. V. Petrov, D. Solomitckii, A. Samuylov, M. A. Lema, M. Gapeyenko, D. Moltchanov, S. Andreev, V. Naumov, K. Samouylov, M. Dohler, Y. Koucheryavy, Dynamic multi-connectivity performance in ultra-dense urban mmwave deployments, IEEE Journal on Selected Areas in Communications 35 (9) (2017) 2038–2055 (September 2017).
8. V. Petrov, M. A. Lema, M. Gapeyenko, K. Antonakoglou, D. Moltchanov, F. Sardis, A. Samuylov, S. Andreev, Y. Koucheryavy, M. Dohler, Achieving end-to-end reliability of mission-critical traffic in softwarized 5g networks, IEEE Journal on Selected Areas in Communications 36 (3) (2018) 485–501 (2018).
9. D. Moltchanov, A. Samuylov, V. Petrov, M. Gapeyenko, H. Nageen, S. Andreev, Y. Koucheryavy, Improving session continuity with bandwidth reservation in mmwave communications, IEEE Wireless Communications Magazine (2018) 1–6 (2018).
10. 3GPP, Study on channel model for frequencies from 0.5 to 100 ghz (release 14), 3GPP TR 38.901 V14.3.0 (January 2018).
11. M. Gapeyenko, V. Petrov, D. Moltchanov, H. Nageen, M. Valkamaa, S. Andreev, Y. Koucheryavy, An analytical representation of the 3gpp 3d channel model parameters for mmwave bands, in: Mobile Computing and Networking (Mobicom), 2018 Annual International Conference on, ACM, 2018, pp. 1–7 (2018).
12. M. Gapeyenko, A. Samuylov, M. Gerasimenko, D. Moltchanov, S. Singh, M. R. Akdeniz, E. Aryafar, N. Himayat, S. Andreev, Y. Koucheryavy, On the temporal effects of mobile blockers in urban millimeter-wave cellular scenarios, IEEE Transactions on Vehicular Technology (2017).