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The impact of breakdowns disciplines and repeated attempts on performances of Small Cell Networks

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ABSTRACT

This paper aims at presenting an approach to study performance and reliability of Small Cell Networks, taking into account the retrial phenomenon, the finite number of customers (mobiles) served in a cell and the random breakdowns of the base station channels. We consider the classical disciplines namely, active and dependent breakdowns and moreover we propose new breakdowns disciplines, in which we give to the interrupted customers due to a channel failure, a higher priority compared to other customers. To this end, we use the Generalized Stochastic Petri Nets (GSPNs) model as a support. However, one of the major drawbacks of this high-level formalism in performance evaluation of large networks is the state space explosion problem which increases when considering repeated calls and multiple unreliable channels. Hence, the novelty of this investigation is the presentation, for the different breakdowns disciplines with and without priority, of an approach which allows a direct computing of the infinitesimal generator describing the customers behavior and the channels allocation in as small cell, neither generating nor storing the reachability set. In addition, we develop the formulas of the main stationary performance and reliability indices, as a function of the network parameters, the stationary probabilities and independently of the reachability set markings. Through numerical examples, we discuss the effect of retrials, breakdowns disciplines and the priority on performances.

1. Introduction

The ever-increasing number of customers and the need for higher data rates and multimedia services require the deployment of Small Cell Mobile Networks (SCNs), which represent a novel networking paradigm based on the idea of deploying short-range, low-power, and low-cost base stations operating in conjunction with the main macro-cellular network infrastructure. Small Cells operate in licensed and unlicensed spectrum that have a range of 10–200 m, compared to a mobile macrocell which might have a range of a few kilometers. The use of SCNs is envisioned to enable next-generation networks to provide high data rates, allow offloading traffic from the macro cell and provide dedicated capacity to homes, enterprises, or urban hotspots. SCNs encompass a broad variety of cell types, such as micro, pico, femto cells, as well as advanced wireless relays and distributed antennas.

Because of the high level of quality of service required by the subscribers (customers) in cellular mobile networks and the fact that more and more important applications in telephone, banking and airline companies depend on the correct and timely operation of these networks and often require a particular quality of service, even in the presence of failures which may have a negative influence on the network performances, the reliability study of these networks is of great importance. Therefore, this paper aims at presenting an approach for performance and reliability analysis of Small Cell Networks by considering a mobile network where a supported area is divided into small cells, each of them is served by a base station having a limited number of channels. This study takes into account the repeated calls of blocked customers, the finite number of customers (mobiles) served in a cell because of its limited capacity and also the random breakdowns of the base station channels.

We consider the classical disciplines namely, active and dependent breakdowns which we have already studied in Ref. [1] and moreover we propose new breakdowns disciplines, in which we give to the interrupted customers due to a channel failure, a higher priority to be served, compared to other customers. To this end,

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we use the Generalized Stochastic Petri Nets (GSPNs) model as a support. From a modeling point of view, this high-level formalism allows an easier description of the behavior of complex systems, which is particularly true for cellular mobile networks. Moreover, it is convenient for generating automatically the corresponding Markov chain for the performance analysis. However, one of the major drawbacks of this formalism in performance evaluation of large networks is the fact that the analysis process requires the generation of the reachability graph and then its reduction to obtain the corresponding Markov chain. These two steps require a large storage space and a long execution time. In addition, the state space increases exponentially when considering repeated calls and multiple unreliable channels.

Hence, the novelty of this investigation is the presentation of an approach that profits from the structured representation of the associated Markov chain to deal with this problem. To this end, we developed for the different breakdowns disciplines of channels with and without priority, an algorithm which allows a direct computing of the Markov chain infinitesimal generator describing the customers behavior and the channels allocation in as small cell, without generating the reachability graph nor its reduction. In that way, the storing of the entire state space is avoided. In addition, we developed the formulas of the main stationary performance and reliability indices, as a function of the network parameters, the stationary probabilities and independently of the reachability set markings.

The paper is organized as follows: First, we present the related works. Next, we give the mathematical description of Small Cell Networks with retrials and channels breakdowns. In Section 4, we describe the syntax and semantics of GSPNs formalism. In Section 5, the models for active and dependent breakdowns disciplines with and without priority of interrupted customers are developed. Then, the proposed analysis approach is detailed for each breakdowns discipline. In Section 7, the computational formulas for evaluating exact performance and reliability measures of these models are derived. Next, based on numerical examples, we discuss the effect of the system parameters, the breakdowns disciplines and the priority on the performability of the network. Finally, we give a conclusion.

2. Related works

Over the last two decades, there has been an increasing interest in the investigation of models with retrial phenomenon (or repeated calls) which is mainly explained by the important role they play in various practical areas as telecommunication, computer networks, cellular mobile networks [8,13,16] and wireless sensor networks [18]. These models with retrials are characterized by the fact that a customer finding all servers busy or unavailable, is not put in a queue, but is obliged to leave the service area, and after some random time, he will repeat his request to try again to reach the servers. Significant references reveal the non-negligible impact of repeated calls, which arise due to a blocking in a network with limited capacity resources or are due to impatience of customers. For a comprehensive review of the theoretical and fundamental methods, results and applications on this topic, the reader is referred to [5–7,10].

Although the importance of reliability study, there are only few works that take into consideration retrial phenomenon involving the unreliability of the servers and the finite source of customers, as it can be seen in the recent classified bibliography of Artalejo [5]. Moreover, most studies deal with single unreliable server retrial queueing systems or an infinite customers source [3,4,14,15,17]. Regarding finite-source retrial queueing models with single unreliable server, the MOSEL tool was used to formulate and solve the problem [3,4,14,15]. However, papers treating finite-source retrial systems with multiple unreliable servers are fewer. The unreliable heterogeneous servers case was considered by Sztrik [12] using a retrial queueing model. On the other hand, retrial mobile networks with several homogeneous servers subject to breakdowns were modeled and analyzed by means of Generalized Stochastic Petri Nets (GSPNs) in the recent paper of Gharbi [11].

Compared to retrial queueing models, the GSPNs formalism allows an easier modeling of the behavior of complex networks. However, the state space increases exponentially when considering repeated calls and multiple unreliable channels. So, we propose in this paper, for the different breakdowns disciplines of channels, an approach that allows a direct computing of the Markov chain infinitesimal generator describing the customers behavior and the channels allocation in as small cell, without generating the reachability graph nor its reduction.

3. Mathematical description of SCNs with retrials and channels breakdowns

We observe a cellular mobile network where a supported area is divided into small cells, with a finite number of customers (mobiles) of size N in each cell and a base station that consists of c ($c \geq 1$) identical and parallel channels subject to breakdowns and repairs. Each customer is either free, under service or in orbit at any time. Each channel can be in operational (up) or non-operational (down) state, and it can be idle or busy (on service).

Free customers generate the so called quasi-random input of primary calls with rate λ. These requests are assigned to operational idle channels randomly and without any priority order. If one of the channels is *up and idle* at the moment of the arrival of a call, then the customer starts being served immediately. Service times are assumed to be independent identically-distributed random variables, whose distribution is exponential with parameter μ. After service completion, the channel becomes idle. Otherwise, if all channels are busy or down at the moment of the arrival of a request, the customer joins the orbit to repeat his call after an exponential time with parameter ν.

A channel can fail in idle or busy state. The breakdowns times of all channels of the base station are assumed to be independent and exponentially distributed with rate δ if the breakdown occurs in idle state and with rate γ in busy state. We classified the breakdowns disciplines into two classes:

- **Interrupted customers disciplines without priority:** In this case, three breakdowns disciplines were defined in the literature:
  - *The active breakdowns discipline* [3,12,17]: when $\gamma > 0$ and $\delta = 0$. In other words, a channel can fail only in busy state.
  - *The independent breakdowns discipline* [3,12]: when $\gamma = \delta > 0$. In this case, a channel can fail in busy or idle state with the same probability. This is a particular case of the dependent breakdowns discipline.
  - *The dependent breakdowns discipline* [11]: In this case, a channel can fail in busy or idle state and the failure probability depends on the channel state. Hence, the failure rates $\gamma > 0$ and $\delta > 0$ are not necessarily equal.
- **Interrupted customers disciplines with priority:** In this case, we consider:
  - The active breakdowns discipline with priority of interrupted customers.
  - The dependent breakdowns discipline with priority of interrupted customers.

As usual, we assume that the inter-arrival periods, service times, retrial times and breakdowns times are mutually independent.