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THE MAINTANANCE STATEGY OPTIMIZATION OF BASE STATIONS OF COMMUNICATION CELLULAR NETWORK

In this paper was presented the method for solving the problem of parametric optimization of maintenance strategy of cellular communications network, whose base stations were located at a considerable distance from each other and from the service station. Maintenance of all base stations carried out by one repair team. Repair team has been given a task to do two types of work: disaster recovery and planning-preventative maintenance. Two variants of realization of maintenance strategy were considered in this paper. Disaster recovery in absolute priority over the planned-preventative maintenance of base stations in the first variant. In another variant disaster recovery carried out after the planned-preventative maintenance of base station. The criterion for optimization is a minimum of maintenance costs, where the availability factor of cellular communication network must measure up of the specified value. It was proposed two mathematical models of realization variants of technical maintenance strategy for this problem solution.

Keywords: *maintenance, maintenance strategy, cellular network, reliability, reliability enginiring, modeling.*

Introduction

High reliability of equipment base stations (BS) of cellular communication network (CCN) is provided by using of fault tolerant systems (with injection of different types of redundancy), using a reliable element base, quality control and elimination of defects during production. The main way to support and provide a specified level of reliability during CCN BS exploitation is the maintenance which involves performing different kinds of recovering actions for occured faults elimination and action for prevents these faults.

Two types of recovery work (repair works (RW) and planned preventative maintenance (PPM)) are provided in the performance of a typical maintenance BS CCN. Restoration works are carried out to eliminate accidents that have arisen at the BS for immediate recovering of its operability. Planned preventative maintenance of BS is carried out to eliminate hidden failures and in order to prevent BS failures.

Recovery works assigned a higher priority for faster failure elimination in the BS and network operability recovers. Rules and carrying out sequence of such recovery works are forming the appropriate maintenance strategy [1]. Choosing the right maintenance strategy and its parameters is a main key factor to maintain the re-quired reliability level of CCN in exploitation phase.

Choosing an effective strategy and optimization of its parameters is difficult task since it requires at the same time take into account many different factors: mainte-nance system assigning; the BS operating conditions and their location relative to maintenance station; the possibility of recovering works; the number of teams that are carrying out the services; given values of reliability must be achieved by maint-ance carrying out.

Along with this it should be also taken into account that the use of a maintenance strategy requires economic costs related to: execution of recovering works; carrying out preventative maintenance; salary costs of personnel which provides mainte-nance; the cost of repair parts and costs for arriving to the BS from maintenance station and so on. So the strategy choice it is nessesary to be considered not only achieves the required values of reliability, but also economic costs.

Thus a reasonable choice of base station CCN maintenance strategy is actual sci-entific problem whose solution would help to improve the quality of mobile services and reduce operating costs of equipment which provides these services.

Approaches of solving problem of maintenance strategy formulation and optimization

Nowadays problem of maintenance strategies analysis was considered in many sci-entific works. Maintenance strategies assessment based on systems reliability indices with taking into account the economic costs based on mathematical models devel-opment of which is considered in works of such scientists: B. P. Kredentser [2, 3], E.Y. Barzilovych [4, 5], F. Bayhelt [6], V.A. Kashtanov [1, 7], A.P. Volokh [3, 8], I. O. Machalin [9] and others. Based on the developed models authors are considering methods of problems solving and select effective maintenance strategies and optimi-zation of their parameters. However an adequate model for strategy maintenance and repair of BS CCN which were considered among presented models were not found. This is explained by the following features of existing models:

– models are usually considered by carrying out of maintanance of one sysytem, and therefore does not allow to analyze maintanance of CCN which consist of a set of the BS situated at a distance from one another [4, 5];

– maintenance and repair process is considered like one-step process. This condition can not adequately assess the strategy maintenance and repair the BS CCN be-cause their maintenance process consists of several stages: preparation stage of repair team to cary out the type of work; stage of repair team staying on the way to the the BS; stage of recovering works directly on the the BS [1, 6, 7];

– models do not take into account that sometimes during planned BS maintenance the there is the need for its disconnection. This limitation leads to a decrease of developed model adequacy and overstating CCN aviability factor values;

– one repair team is assigned to this works in modern terms to reduce the costs as-sociated with carrying out maintenance and repair. Most existing models provide that maintenance and repair is carried out in two different repair teams [2, 3, 8].

For determining the economic costs there is known approach according to which it is necessary to estimate the average unit costs per unit of time spent in system work-ing condition. It should be noticed works [2, 3, 8] in which is described the general meth-odological approach of approving of maintenance strategies choice of weapons and military equipment with the use of cost quality index function. This approach is based on determination and comparisons economic and probabilistic characteristics of the object exploitaion process during the realization of different service strategies. Developed in this paper formulas of economic indices calculation takes into account the recovery costs, maintenance and control of technical condition. But these formu-las are suitable only for evaluation maintenance cases of one object with the as-sumption that the maintenance process is considered like one-step process.

In work [10] the formulas of average unit costs per unit of time spent in CCN oper-able state are proposed which allows considering maintenance and repairing as multi-stage process.

Thus there are two unsolved problem today that arise in a approving of mainte-nance strategy BS cellular network communication. The first task consists of the necessity of developing appropriate mathematical model that can reflect the process of large objects sets maintenance with high degree of adequacy which are part of a complex system and consider all the subtleties of behavior repair service during maintenance or repair. The second task consists of economic efficiency assessing of used maintenance strategy.

Analysis of a base stations typical mainte-nance and repair proccess in order to build model as a queuing system

Recovering works procedure

Communication cellular netwrok BS are under permanent control of monitoring sys-tems. Therefore, after failure occurrence which leads to loss BS of effi-ciency the ser-vice center is immediately notified about this accident situation. In service center the preliminary analysis of accident situation is performed after receipt of message from the monitoring systems. Based on the reports of the accident that was occurred the service center forms and sends a message to the repair service about the need for RW. Repair service initiates action of maintenance teams. Scheme which illustrates the se-quence of actions when the message about the accident on CCN BS was oc-curred is shown in Fig. 1.

Repair service is required of during the set time to send a confirmation a message receipt to a service cen-ter about receiveing message from the service center about accident situations in BS. After this repair teams which are responsible for the maintenance of BS are carrying out a preliminary analysis of information about this accident.

Based on this information repair team determines a necessary to repair equipment and amount of spare parts. After preparatory works the repair team makes departure to BS location in which accident situation was occured. On arrival on BS repair team carries out a de-tailed investigation of the accident situation that has arisen and de-fines its causes and also sends a message to a service center with detailed report of accident. After investigation of accident situation, the repair team be-gins to make repair proccess. After all necessary renew-als actions the repair team sends confirma-tion message about successful troubleshooting and returns to the maintenance sta-tion.

Procedure of prevent maintenance

On the BS the failures which could not be detected by the monitoring system could be occured. Such fail-ures are parametric failure, progressive failure (drift pa-rameters of aging equipment, operating mode drift). These failures do not lead to BS fault but if any of it is occurred on BS the probability of accident occurrence in BS is increasing. Such failures are called hidden and their detection is possible only when repair teams are on BS. To troubleshoot hidden failures in BS the PPM should be provided.

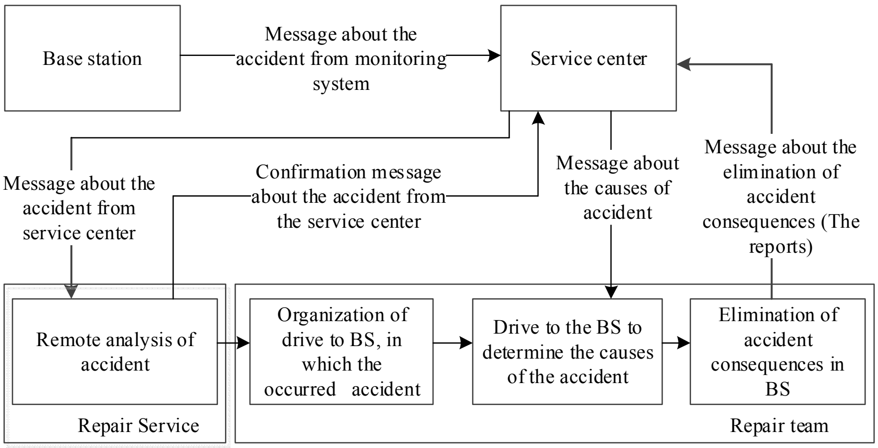

Fig. 1. Scheme which illustrates the sequence of actions when the message about the accident on CCN BS was occurred

Planned preventative maintenance of BS takes place in scheduled time which is defined by exploitation technical conditions of equipment which is located in these BS. Start of PPM work is directly determined in the service center by following pre-defined schedule.

In specified calendar time the service center sends a message to the repair service about the necessity about BS PPM. Repair service within the prescribed time is re-quired to send confirmation of receipt to a service center. Then repair team which is assigned to appropri-ate BS is making departure to it for PPM.

After arrival to BS location the repair team is car-rying out a series of checks and maintenance works which are clearly established in norms of appropriate exploita-tion system. After the base station PPM the repair team returns to the maintenance station and sends a message to a service center about end of PPM with information about the made works and the problems that have been troubleshooted.

Only one repair team is used to make PPM and RW cellular network connection BS.

Development of a strategy maintenance and repair of base station of cellular net-work connection mathematical model

Presentation of strategies maintenance and re-pair of base stations of cellular communication net-work as a queuing system

Strategy for maintenance and repairs for this object after reviewing procedures for PPM and RW with tak-ing into account the structure of the network is repre-sented as queuing system (QS) in Fig. 2.

In this model, unlike of existing models [1, 7, 11, 8, 2, 3, 4-6, 9, 12-16] is considered that the RW and PPM are made by one repair teamand is detailed showed all stages of the recovery works and taken into account the shutdown of BS during PPM.

Developed QS consists of three applications queues (queue of requests for PPM; fictitious queue of applications for troubleshooting of hidden failures; the queue of requests for RW) and service channel (SC).

The queue of requests for PPM reflects the current value of the number of base stations CCN in which PPM must be carry out. The maximum size of the queue

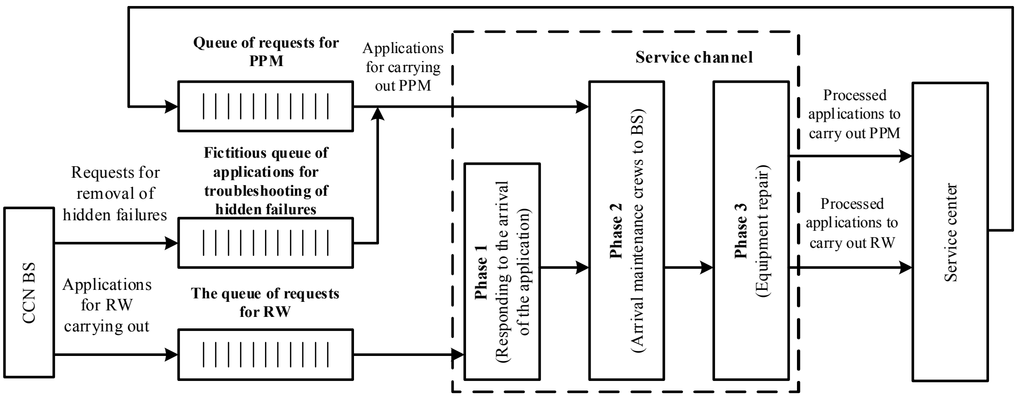

Fig. 2. Queuing system with three queue and singled channel multiphase service

is determined as the number of base stations that are in the service of one repair team.

Fictitious queue of troubleshooting of hidden failures reflect the current number of base stationsin in which hidden failure have arisen. The model provides that all hidden failures in one BS are included in one application. Thus the maximum size of the queue of hidden failures troubleshooting depends on the base stations numbers which are serviced by one repair team.

The queue of requests for WR shows the current number of accidents that have occurred on BS. Maximum size of the requests queue for WR depends on the number of base stations which are serviced by one repair team since each base station is in-herent in one accident situation.

In developed model PPM and RW are presented as SC of multiphase service in which each phase reflects appropriate stage of reneweal works.

In mathematical model developing the process of BS maintenance a number of assumptions were adopted:

It is proposed that the length of the processes that occur in the proposed queuing is distributed by exponential distribution law. This condition arises in due to the aid of Markov random processes theory.

It is proposed that all base stations have the same priority. This assumption makes possible to calculate CCN reliability indices which includes a large number of BS and efficiency indexes of maintenance strategy based on simulation of mainte-nance of systems process which are serviced by one repair team.

It is assumed that any accident situation that arises in BS regardless of whether it leads to a complete BS failure or partial disability or simply to worsening functional parameters is critical. So all accidents that occur in the BS are reduced to one and their presence leads to BS fault. This assumption allows preventing the state space overgrowth in proccess for building of the graph of states and transitions.

Also to prevent the overgrowth state space in process for building of the graph of states and transitions all hidden failures in a are summarized.

Features of maintenance strategies of communication cellular network base stations with absolute and relative service priority

According to the proposed queuing system description let's make description about maintenance strategies with absolute and relative service priority.

Maintenance requests for PPM. At the initial time queue of requests for PPM is filled. The number of applications that are in the queue is equal to the number of BS which are in the service of repair team. If the BS which are serviced there are no acci-dents and it means that queue of requests for RW is empty, the requests that are in queue for PPM are coming to CS service. Services of the following request for PPM can not begin until the previous request is not serviced which means that there could be serviced only one request.

With the strategy of absolute priority service there are few conditions. If during the service requests of PPM to queue incomes request of RW in realtions of higher priority requests of RW becomes for servicing and request of PPM is terminated CS and CS receives requests of RW that had income in queue. Services requests for PPM would not be serviced until all requests for RW would be processed.

In strategy relative service priority there is next scenario. If during BS PPM to a service center is received an message about accident situation on another BS the repair team first must finish started PPM and after it begins to make a recovering works in another BS.

In all other situations the strategy with relative service priority is similar to strategy maintenance with absolute service priority.

Services requests for RW. Requests of RW are incoming into service center with certain intensity (intensity of accidents BS). If at the present time of receipt request for RW in CS there is earlier received request for RW the request which has just in-come gets in queue for RW.

Services requests for hidden failures troubleshooting. Requests for hidden failures troubleshooting are incoming to fictitious requests queue with intensity. Hidden failure detection is possible only when the repair team is directly on the base station. Therefore, requests service for the hidden failures troubleshooting is performed only when PPM requests are servicing. Moreover, it is considered that the length of pro-cessing requests for the hidden failures troubleshooting already laid down in the value of the average duration of processing PPM requests if the request for the hidden failure troubleshooting is served with a request for PPM.

Procedure of requests staying in the channel service. Service of requests for RW and PPM in SC is performed on the same principle. Requests services for RW is oc-curing in three phases and requests service for PPM is occuring in two phases. Lack the first phase of requests service for PPM is because the at PPM carrying out the repair team makes no advance preparation before departure to the BS location be-cause the type and quantity of necessary spare parts and tools for PPM are before-hand defined by BS standards operation.

The first phase of the request service in SC reflect the preliminary preparation of repair team of RW start. The duration of request for the first phase is equal to repair team preliminary preparation work duration T_{pr}.

The second phase of requests service reflects in SC the repair team department to system on which RW must be carried out. Duration of requests service second phase is determined as the average time that spends for repair team for arrive to BS and equal to T_a .

The service requests third phase in SC reflects the process of recovery work on the BS location. The duration of requests for the third phase is determined by the average time of recovery work and BS level of T_{PPM} – for requests for PPM and T_{RW} – for requests for RW.

Development of a queuing system mathematical model as a system of differential equations Chapman - Kolmogorov

Was analyzed papers on the problem of modeling queuing systems [17-20]. In these works not found models for QS with three queues and multiphase service Fig. 2. Therefore, it is necessary to carry out the building of a mathematical model for pro-posed QS and make formation of the required functional performance of CCN maintenance. The development of a QS mathematical model is based on theory of Markov processes [21]. The mathematical representation of this model is a system of differential equations Chapman - Kolmogorov (with constant coefficients). Based on the equations system solution is carried out the formation of required performance indexes (CCN reliability indexes, Maintenance efficiency indexes). For the differen-tial equations system the graph of states and transitions should be building. Graph of states and transitions displays all possible states in which system could be and possi-ble ways of getting all these states.

The main problem that arises in graph of states and transitions building is a signif-icant growth of states space with taking into account the structural features of the investigated system and behavior of failure with detailed consideration and recovery processes that occur in this system. Large state space dimension complicates its anal-ysis process and manual construction could lead of mistakes making. In many works [2, 3] in and analysis of graph states and transitions building and analysis there is carried out consolidation of states which simplifies the process of analyzing it but this consolidation reduces the adequacy of the model and decrease the accuracy of the results.

In work [21] the technology of building of behavior models of discrete-continuous stochastic systems (DCSS) which in combination with the software module ASNA [22] allows for automated building a graph of states and transitions. Technology [21] in-volves the following steps: forming verbal model, structural automaton model design, forming the necessary efficiency indexes based on the values of probabilities of stay-ing system in each state. Each of these stages is a separate technical task.

Detailed development of mathematical models in the form of a linear differential equations system for the two variants of realization maintenance strategy with abso-lute and relative service priority of CCN BS is presented in [10].

Result of solving of linear differential equations systems is the probability of be-ing the subject of research in all states. Based on these probabilities the required CCN parameters of reliability and efficiency of relevant maintenance strategy could be calculated.

Development of formulas for calculating of the average unit costs per unit of time spent of CCN in working condition with multiphase maintenance

To calculate the average unit costs per unit of time spent in working condition CCN is necessary to identify types of work carried out during maintenance BS and specific expenses that occur during the execution of these works. According to description of the BS maintenance process the two types of recovery work could be distinguished which are carried out in order to ensure an appropriate level of reliability for the entire period of exploitation. This is PPM which is performed for regular execusion in order to detect and prevent potential system failures (its components) and ensure continu-ous efficiency and working state of system and recovery operations which are per-formed by repair service in order to restore its operational efficiency and working state of the system.

The process of this work has a few stages. According to the carried out description to the process of RW there are three main stages:

Step 1. Respond of repair team to incoming request.

Step 2. Staying repair team on the road to the BS.

Step 3. Staying repair team in BS location for working on PPM or RW.

In turn PPM process is characterized only stages 2 and 3. Stage 1 is not presented at the fact that the process of planning and the BS visit is choosed by repair team based on the established norms of PPM frequency.

Developed models take into account all the stages of the recovery work what can solve the problem of choosing the effective values of the average time allocated to each stage. Unlike in existing models this feature of the developed model allows to calculate of specific costs per unit of time spent CCN in working condition wiht tak-ing into account the total costs attributable to the process of maintenance and the costs that occurs during each stage. This allows for a deeper analysis of mainte-nance.

According to the method presented in [2] it is necessary to identify the specific costs per unit of time spent in system conditions that reflect the respective stage of system recovering. Stay repair team at each stage of the respective recovery work according to [10] has the following specific expenses:

c_{pr} – specific costs per unit of time spent on repair team on phase response to the arrival of requests for

RW;

c_a – specific costs per unit of time spent on the road of repair team to BS;

c_{RW} – specific costs per unit of time spent on repair team of RW stage on BS;

c_{PPM} – specific costs per unit of time spent on repair team of PPM stage on BS.

At long exploitation of the system the average unit costs per unit of time spent CCN in working condition according to [10] is calculated as follows:

$$\overline{C} = \frac{c_{pr} \cdot K_{pr} + c_a \cdot K_a + c_{MMP} \cdot K_{MMP} + c_{RW} \cdot K_{RW}}{Av} \quad (1)$$

where K_{pr} – total share of time spent on phase when repair team response on incoming requests for RW;

K_a – total share of time spent on phase for arriving the repair team to BS;

K_{RW} – total share of time spent on repair team of RW stage on BS;

K_{PPM} – total share of time spent on repair team of PPM stage on BS;

Av – availability factor.

Select the strategy of maintenance and repair depending on the location of the service center of base station CCN

In maintenance carrying out it could be presented instances when during the execution of one PPM on base station CCN an accident situation arises on another base station. When using maintenance strategies with absolute service priority the repair team stops PPM and returns to the maintenance station in order to begin RW of an occured accident situation. After the RW the repair team returns to the base station to continue PPM. In the event of such situation it can be seen that the repair team performs twice departures to BS for PPM. First time planned and second unplanned time in order to complete the PPM which was interrupted. This strategy provides maintenance and repairs for quick elimination of accidents which were occurred. However, its use causes for increasing travel expenses in comparison with the strategy maintenance and repair with relative service priority.

To determine effective strategies maintenance and repair lets research performance indexes (CCN availability factor, the average unit costs that fall on CCN staying in working state) at different durations of traveling the repair teams to the base station with different distances from the base station which is serviced maintenance station.

Analysis of maintenance strategies is performed with next input data:

– number of base stations that are in service $N = 5$;

– intensity requests receipt for RW (intensity of accident situations on BS) $\lambda = 1 \times 10^{-4}\ h^{-1}$;

– intensity of request receipt for troubleshooting of hidden failures (intensity of hidden failures occuring in BS) $\lambda_h = 1 \times 10^{-3}\ h^{-1}$;

– average the duration of the first requests service phase for RW (time spent on the formation and training of repair team) $T_{pr} = 0,5$ h;

– average the duration of the second requests service phase for RW and the first requests service phase for PPM (time spent on the road to a BS) $T_a = 3$ h;

– the average the duration of the second phase of service requests for PPM (time spent on PPM work on BS location) $T_{PPM} = 5$ h;

– the average theof duration of the third phase of service requests for RW (time spent to carry out RW on BS location) $T_{RW} = 3$ h.

The following conclusions from the obtained dependencies for this set of input data could be noticed:

– if the average duration of arriving to BS from station maintenance of repair team is no more than two hours and it is advisable to use strategy with absolute service priority that provides more operability BS coefficient than maintenance strategy with the relative service priority and unit costs for two maintenance strategies are equal;

– if the average duration of arriving to BS from station maintenance of repair team is more than two hours and it is advisable to use strategy with relative service pri-ority because it gives bigger BS operability coefficient than maintenance strategy with the absolute service priority of and unit costs are less.

Comparison of obtained results based on proposed mathematical models and known maintenance strategy base stations cellular network connection

To confirm desirability of new models strategies maintenance repair CCN developing based on the above approach lets make comparative research of strategies efficiency indexes which were obtained by using the proposed and known models. Known model has a differs from proposed model which is preented in that in it all the stages of the recovery work are combined in one procedure "recovery" and it does not distinguish between different stages of recovering.

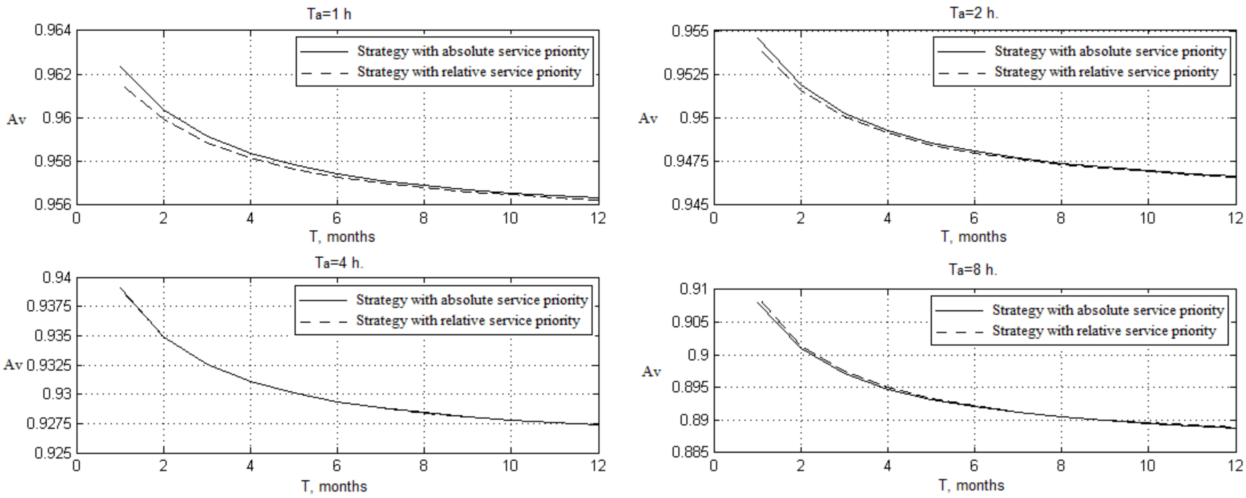

Fig. 4. Graphs of CCN operability dependence on the periodicity of maintenance for different values of the duration of arriving to BS

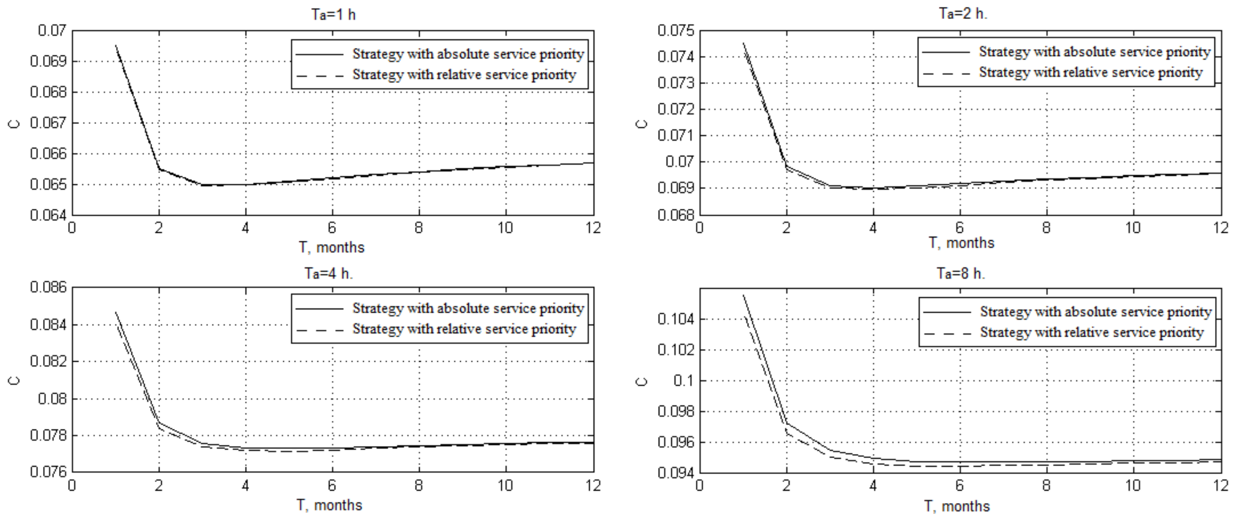

Fig. 5. Graphs of dependence average unit costs per unit of time spent CCN in working condition on the periodicity of of PPM for different values of the duration of arriving to BS

Comparison of efficiency indexes was carried out in next input data for proposed models with two variants of maintenance strategies realization:

c_{pr} – specific costs per unit of time spent on repair team on phase response to the arrival of requests for RW $c_{pr} = 100\,{}^{hrn}\!/_{h}$;

c_{RW} – specific costs per unit of time spent on repair team of RW stage on BS $c_{RW} = 3000\,{}^{hrn}\!/_{h}$;

c_{PPM} – specific costs per unit of time spent on repair team of PPM stage on BS $c_{PPM} = 1500\,{}^{hrn}\!/_{h}$;

c_a – specific costs per unit of time spent on the road of repair team to BS $c_a = 100\,{}^{hrn}\!/_{h}$.

For this research inputs which was bring in the previous paragraph are used.

The research results demonstrate the differences between the values of efficiency indexes maintenance strategy CCN obtained by the proposed models and efficiency indexes values obtained by the well-known model which does not distinguish stages of recovering. This demonstrates the expediency development of complex models with high adequacy display maintenance strategies to produce precise values of efficiency maintenance strategies of base station communication cellular network.

Conclusion and future work

This paper presents the method of solving the problem of choosing an effective strat-egy for

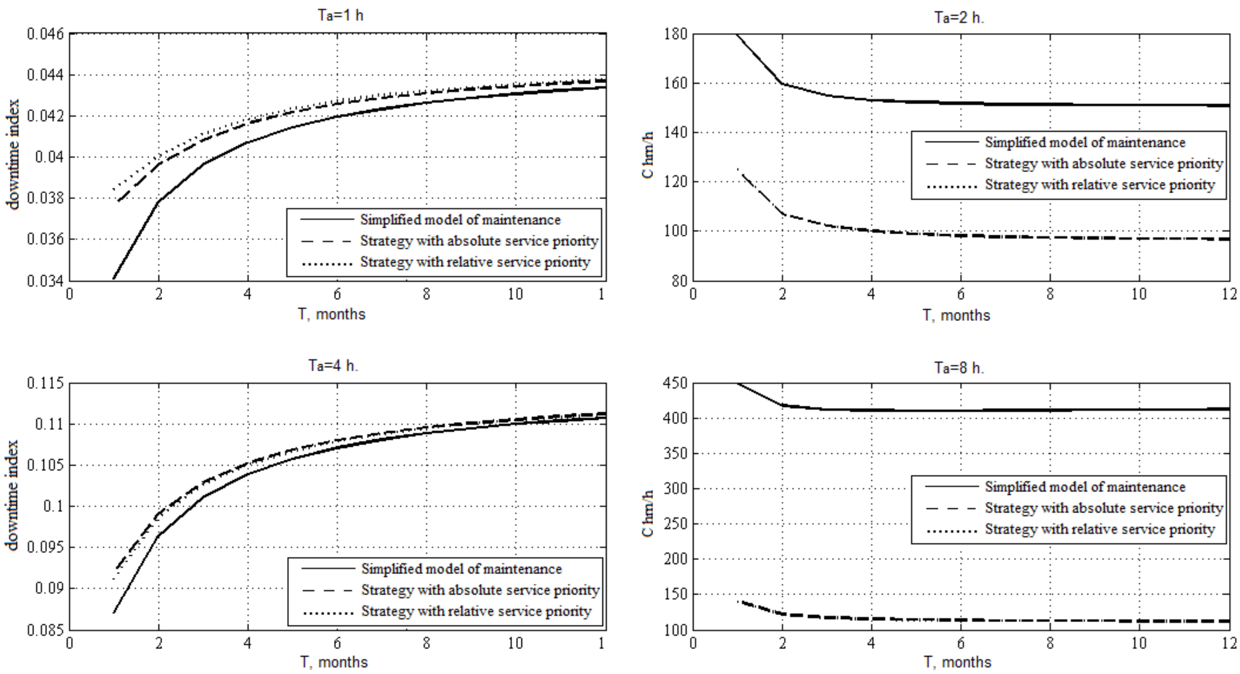

Fig. 6. Dependence of simple and average unit costs per unit of time spent CCN in working condition on the periodicity of PPM

maintenance and repair of cellular network communication base station from the set of competitive strategies with optimal values of the parameters of the criterion of minimum expenses for maintenance and repairs on the condition of its reliability. The method is illustrated by solving a specific problem. For this mathematical models and repair maintenance strategies were developed which take into account: the loca-tion of the base station; multi-stage maintenance and repair; repair team perform one of two types recovery work (planned maintenance and faults recovery); base station shutdown during maintenance. Proposed multi-stage maintenance and repair models allows for differentially assess the value of different maintenance stages.

For a particular set of input data comparison of efficiency indexes strategies for maintenance and repair with absolute and relative priority of service were made. Recommendation for choosing the best strategy for maintenance and repair depend-ing on the arriving the repair team from the service center to the base station cellular network communication were formed.

A comparison of efficiency indexes strategies for maintenance and repair ob-tained using the proposed models and known simplified model which does not distin-guish different between stages of recovering system were carried out. Researches have shown that the use of the developed model permits of increasing the accuracy of calculation of the reliability indexes (downtime coefficient) to 11% and average unit costs per unit of time spent CCN working state to 220%.

Results of this article open the possibility of effectiveness research of new strategies for cellular communication network base stations maintenance and gives possibility to optimize system parameters in specific conditions.

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ОПТИМІЗАЦІЯ СТРАТЕГІЇ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ БАЗОВИХ СТАНЦІЙ МЕРЕЖІ КОМІРКОВОГО ЗВ'ЯЗКУ

Б. Ю. Волочій, Л. Д. Озірковський, І. В. Кулик, М. М. Змисний

Представлена методика вирішення задачі параметричної оптимізації стратегії технічного обслуговування мережі коміркового зв'язку, базові станції якої розташовані на значній відстані одна від одної та від станції технічного обслуговування. Технічне обслуговування всіх базових станцій здійснюється однією ремонтною бригадою. На ремонтну бригаду покладено виконання двох видів робіт: аварійне відновлення та планово-профілактичне обслуговування. Розглянуто два варіанти реалізації стратегії технічного обслуговування. В першому варіанті аварійному відновленню надається абсолютний пріоритет над планово-профілактичним обслуговуванням базових станцій. В другому варіанті аварійне відновлення здійснюється після завершення планово-профілактичного обслуговування базової станції. Критерієм оптимізації є мінімум витрат на технічне обслуговування, при якому коефіцієнт готовності мережі коміркового зв'язку має відповідати заданому значенню. Для розв'язання поставленої задачі запропоновано дві математичні моделі варіантів реалізації стратегії технічного обслуговування.

Ключові слова: технічне обслуговування, стратегія технічного обслуговування, мережа коміркового зв'язку, надійність, надійнісне проектування, моделювання.

ОПТИМИЗАЦИЯ СТРАТЕГИИ ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ БАЗОВЫХ СТАНЦИЙ СЕТИ СОТОВОЙ СВЯЗИ

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Представлена методика решения задачи параметрической оптимизации стратегии технического обслуживания сети мобильной связи, базовые станции которой расположены на значительном расстоянии друг от друга и от станции технического обслуживания. Техническое обслуживание всех базовых станций осуществляется одной ремонтной бригадой. На ремонтную бригаду возложено выполнение двух видов работ: аварийное восстановление и планово-профилактическое обслуживание. Рассмотрены два варианта реализации стратегии технического обслуживания. В первом варианте аварийному восстановлению присвоен абсолютный приоритет над планово-профилактическим обслуживанием базовых станций. Во втором варианте аварийное восстановление осуществляется после завершения планово-профилактического обслуживания базовой станции. Критерием оптимизации является минимум издержек на техническое обслуживание, при котором коэффициент готовности сети мобильной связи должен соответствовать заданному значению. Для решения поставленной задачи предложены две математические модели вариантов реализации стратегии технического обслуживания.

Ключевые слова: техническое обслуживание, стратегия технического обслуживания, сеть сотовой связи, надежность, надежностный проектирования, моделирования.

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