Mobile Network Service Demand in case of Electricity Network Disturbance Situation

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***Abstract*—The aim of this study is to analyze how cellular network subscribers behave during an electricity network disturbance situation. Furthermore, removing the effect of randomly accessing the network could improve especially the speech capacity during these events. When part of the mobile network is unavailable, the availability of the cellular network services decreases. However, the subscribers have increased demand for services during disturbance scenarios since they fetch information from the Internet and try to contact their family and friends. The analysis in this paper shows that even an uncommon power blackout resulted in an increase of 73 % in new calls and 84 % in the number of short message service (SMS) demand for mobile network services in a rural area.**

***Index Terms*—Availability, mobile networks, disturbance, disaster, blackout, service demand, rural.**

I. INTRODUCTION

After any major incident, such as a natural disaster scenario, the service demand behavior of mobile network subscribers changes. Traditionally, the large-scale statistics of the mobile network traffic from any region, like a certain city or even a larger area of a municipality, follow a certain routine day after day. This includes normally: a very low network usage time period during the night; some high service demand hours, the so called busy hours, that occur usually during lunch time or after work hours when people make calls to their families and friends; and other mediocre network usage time periods during the day. This cycle repeats day after day and has a specific profile which can be noticed from the statistics. The profiles for working days, i.e. from Monday to Friday, are very similar, but the profiles for the weekends are slightly different. This can actually be already noticed on Friday evenings as subscribers tend to prepare for the weekend, thus usually increasing the service demand.

The mobile network traffic profiles tend to repeat similarly week after week. It is also normal to observe a change in the traffic profiles when the season changes, e.g. from spring to summer as people have holidays that break the normal cycle. If there are some major changes or uncommon events, their affect can also be noticed from the statistics. A large gathering of people can be noticed from the statistics with increased traffic and blocking rates as the mobile network capacity is not dimensioned for these events. They can include, among others, rock concerts, sports events or festivals that gather massive amounts of people. Thus, the network at these locations can not meet the demand requirements set by the temporarily increased number of subscribers and results to lack of service for the portion of the demand that exceeds the planned service capacity for that specific area. However, there is usually some information available in advance for these kind of events and mobile operators can set up some extra capacity with movable base stations (BSs) for these areas in order to temporarily increase the capacity to meet the expected service demand increase.

This is not the same for sudden, unexpected network disturbances or disaster scenarios. These can include, among others, storms that cause destruction to electricity networks resulting eventually in power outages. This relates back to mobile network BSs since their functionality depends on the availability of electricity. In Finland, the Finnish Communications Regulatory Authority (FICORA) has assigned that cellular network BSs sites must have backup power for two to four hours depending on the type and the environment of the BSs, i.e. whether the equipment is located inside a private property in urban area or a mast in rural area [1]. This should guarantee that mobile networks continue to operate (voice and data) at least few hours after a power blackout, but this again depends on the condition of the backup batteries or other reserve power at the BS sites with respect to the service demand. However, this does not guarantee the availability of mobile network services at those locations. This is because the service demand increases as the subscriber behavior changes, which results in the cellular network not being able to handle all the increased traffic, i.e. the capacity is not planned to cope with the extra traffic caused by disturbance or disaster scenarios. It should be noted that the behavior of the subscribers might be dissimilar in different environments, i.e. the users in rural areas might be more used to power blackouts than users in urban areas. The cause of the disaster scenario also affects the behavior of the subscribers as large natural disasters will result in more panic among the citizen than an uncommon blackout, e.g. in the electricity network.

This paper presents a study performed in Finland, where one regional electricity network power blackout (caused by a storm) was analyzed from the mobile network statistics point of view. *The target is to show how the cellular network traf-*

fic demand changes according to an unexpected, uncommon event. This helps to understand how the networks should be designed to prepare for possible disturbance scenarios or what are the possible problems that should be taken into account. Furthermore, the situation could be improved with guidelines on how to utilize the network in these disturbance situations with some modifications on the basic principles for accessing the network.

II. BACKGROUND

Mobile network capacity dimensioning is initially based on the number of potential subscribers and some assumptions. These include e.g. how often calls are made and how long these calls should last or what other kind of services could be expected. Moreover, the target is to offer suitable capacity to subscribers with minimal costs, i.e. the network should be fully utilized in the busiest time periods. This way the operators do not have to invest in additional capacity and the network operation should be cost-efficient.

A. Random service access

Mobile network capacity depends heavily on the offered services and the user behavior. A general assumption is that users may move and utilize services freely and randomly anywhere and any time. For traditional speech users, a relatively accurate modeling based on Poisson process can be utilized. In a Poisson process, users have a *random* length of a call and follow the negative exponential curve [2], [3], i.e. the probability density function is defined as

$$p(T) = \mu e^{-\mu T}, \tag{1}$$

where T denotes the time of the arriving call and $1/\mu$ is the average call duration. In addition, users have *random* time between the calls, also following the negative exponential curve and the probability density function is, respectively

$$p(T) = \lambda e^{-\lambda T}, \tag{2}$$

and $1/\lambda$ is the average inter-arrival time. When both the length of the calls and the arrival time of the calls are random, the most interesting value is the probability of a user not being able to make a call. The well-known Erlang-B formula (without queuing) can be defined [3] and the blocking probability p_m is defined as

$$p_m = \frac{\left(\frac{\lambda}{\mu}\right)^m / m!}{\sum_{n=0}^{m} \left(\frac{\lambda}{\mu}\right)^n / n!}, \tag{3}$$

where m is the number of channels that are busy and n is the number of total channels in the system.

Erlang-B formula gives estimation about the available speech traffic of a certain configuration (the amount of channels) when certain blocking probability is expected, and when the subscriber call behavior is random. In [2], a comparison is shown for a traditional one transceiver (TRX) BS having 7 traffic channels (1 channel reserved for signaling) in global system for mobile communication (GSM). Erlang-B formula provides $2.5\,\mathrm{Erl}$ traffic in case of $1\,\%$ blocking probability. Measurements from the real network give $2.0\,\mathrm{Erl}$ traffic and $0.4\,\%$ blocking i.e. practical values follow the theoretical calculations quite well. The theoretical maximum capacity (7 traffic channels, without blocking) would be $7\,\mathrm{Erl}$ if callers have a certain allocated time slot for a service and no gaps exist between the channel allocation in the time domain. Thus, $4.5\,\mathrm{Erl}$ of capacity is missed in order to have freedom for users to make calls randomly, and simultaneously to keep the blocking at the level of $1\,\%$. Thus, *to increase the available capacity in disturbance or disaster scenarios, the randomness of call lengths and times could be temporarily disabled* and specific time slots could be reserved for different users in the disturbance area. For example, in 1 TRX GSM case, capacity can be increased from $2.5\,\mathrm{Erl}$ theoretically up to $7\,\mathrm{Erl}$ (with $0\,\%$ blocking) meaning a notable capacity increase in this very limited configuration. The same $7\,\mathrm{Erl}$ capacity would be achieved with $24.9\,\%$ blocking if randomness would remain. This will obviously need some algorithms to allocate "call slots" so that the subscribers in these areas know when they can make their calls. The emergency calls should get through in all situations, but for the not-so-time-critical-calls this method should provide some fairness among the subscribers, e.g. subscribers can not reserve the channels for too long. A system of this kind would need some method in order to call or notify the subscribers whose time slot to call is up so that the signaling still works without congesting too much.

B. Related work

The impact of disaster scenarios on mobile network traffic has been investigated *mostly after major* natural disasters. The authors in [4] show that the availability of mobile networks was lowered by $32\,\%$ in Hurricane Sandy in 2012. Likewise, the authors in [5] show that the cellular network call amount was increased 60 times the normal demand after the Tsunami had hit Japan in 2011, resulting in a blocking rate of $95\,\%$ for new calls. Thus, the service demand increase is huge in major disaster scenarios. This paper, however, studies the effect of a smaller, uncommon power blackout on the subscriber behaviour.

As a suggestion for these enormous service demands, the authors in [6] show that if the mobile network core is virtualized, the operation of such network can be improved during these events by reprioritizing the cellular network traffic services. They show that when the call traffic has a sudden 50-fold increase, the voice call acceptance rate is around $5\,\%$ without any modifications on the core network. When the core network resources are reallocated, the call acceptance is increased up to $25\,\%$, thus improving the overall situation only by changing the core services.

Some studies ([7], [8]) also suggest automatic algorithms and machine learning to discover anomalous patterns in network traffic to predict when a major event is about to emerge.

This information can be useful, when a sudden incident happens in the network to automatically react to the changed situation. Thus, any kind of uncommon event remarkably changes the subscriber behavior and authors in [9] also show through simulations that the network congestion is mainly caused by the dynamic changes in subscriber behavior.

C. Possible methods to increase the mobile network capacity in disturbance areas

Mobile network coverage is lost without electricity supply if BSs lack backup power. Thus, when a power blackout occurs in the power grid, the mobile network has to rely on backup power to enable mobile network services in the corresponding blackout area. This so called *backup coverage* continues until the backup power runs out, which usually takes up to few hours. The backup coverage should be utilized as efficiently as possible, and the required services should be balanced with the amount of users and the available capacity.

One possibility to maximize the available network capacity is to guide mobile users [10] away from the so called bad locations, i.e. areas where the cellular network environment is the most challenging. These locations include places where the received signal energy is very low and there is a possibility to improve it with small actions, e.g. moving from one room to another, where the received signal strength is higher. This option would indeed restrain the freedom of utilizing the mobile network from anywhere, but disaster scenarios require a different way of utilizing the network in order to maximize at least some availability of the network services.

Another solutions relate to studies like [6], i.e. reprioritizing some elements in the core network to enable more calls in the network. Also, like suggested in the conclusion in [9], the subscribers should be informed and advised to use the cellular network selectively to increase the odds of a successful call completion.

Finally, the solution presented in this paper relies on an idea of taking away the ability of subscribers to randomly access the mobile network. This means that the mobile network operators would have a predefined plan to restrict the normal calls from subscribers during disturbance situations in case the network starts to congest over a predefined threshold. At such event, the operators would send a broadcasting short message service (SMS) to the customers to notify about the change in the network functionality and that the customers should avoid performing calls if possible. The message would also remind the customers what would be the time slot within an hour they could try to make a call.

III. MEASUREMENT RESULTS AND ANALYSIS FROM THE REAL NETWORK

A. Description of the power blackout area

The analysis of this study was performed to a certain area in Finland for one mobile operator. The area was roughly $1500\,\mathrm{km}^2$ in size with a population around 7000 people, in which the mobile operator has roughly 39 % market share. The number of BS sites for GSM network was 19 with 58 cells and correspondingly the number of universal mobile telecommunications system (UMTS) sites was 14 with 62 cells. The raw data consist of GSM and UMTS network statistics gathered before, during and after a power blackout that lasted for several hours. This means that the backup power ran out from most of the BS sites. The power blackout started at 3.30 p.m. on Thursday when half of the regional electricity network of the specific area went down, and at 3.55 p.m. 87 % of the area was missing electricity as seen from Fig. 1. After this, the situation started to improve as repair teams progressed in reconnecting the outage areas back online and around 1.00 a.m. in the next day, i.e. after nine and a half hours from the beginning of the electricity disturbance situation, half of the area had electricity. It then took 11 hours more to around 12 p.m. to reach 90 % availability in the electricity network. The last remaining 10 % of outage areas still took around 12 hours to fully restore the electricity network.

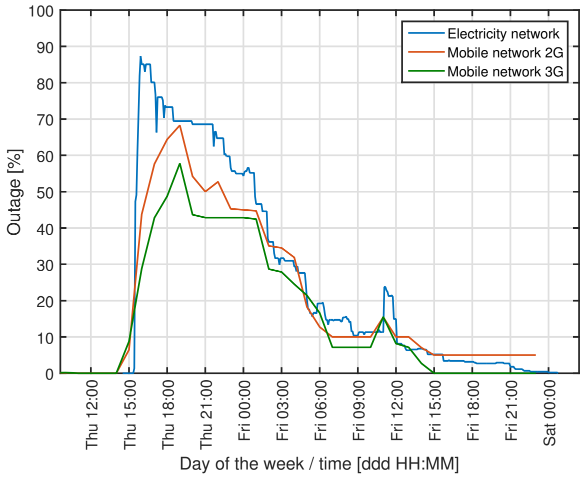


Fig. 1: Outage percentage for both electricity and mobile networks. The date / time format is 'ddd' refering to the first three letters of a day and 'HH:MM' for a time presentation with two digits for both hours and minutes.

Besides electricity, also the outage of 2G (GSM) and 3G (UMTS) mobile network technologies are shown in Fig. 1. The shape follows that of the electricity outage version, which was to be expected. The time resolution for the electricity network is five minutes, but for mobile networks it is one hour. The reason for not having a zero percentage outage for 2G mobile network after fully restored electricity network availability is that one of the mobile network BS sites did not manage to reboot itself automatically. Thus it had to be manually rebooted. It also seems that in Fig. 1 the mobile network outage starts before the electrical network, but this is because of the time resolution and the way the performance data is collected and stored. Events in the network that have occurred, e.g. between 3.00 p.m. and 3.59 p.m., are shown in the data at 3.00 p.m.

B. Mobile network statistics analysis

The figures on the following page, i.e. Fig. 2 and Fig. 3, show the 2G and 3G cellular network statistics before, during and after the disturbance in the electrical network. The green, orange, and blue bars show some selected key performance indicators (KPIs) for Wednesday, Thursday, and Friday, respectively. The solid, dashed, and dotted lines also show the availability of the electricity network for Wednesday, Thursday, and Friday. A numerical summary of the data is shown in Table I after the figures.

Fig. 2a shows how the number of new calls differ for each day. The KPI profile for each weekday is similar, but when the availability of the network drops at 3.00 p.m. on Thursday, there is a spike in the number of new calls. This trend continues for the whole Thursday evening, which indicates that the power blackout has activated subscribers to make more phone calls than usual. The same effect is visible in Fig. 2b; the number of new standalone dedicated control channel (SDCCH) seizures peaks when the electricity blackout begins. The effect is also visible during the night between Thursday and Friday, i.e. in the early hours of Friday, most likely due to repair workers. This is because besides call setups SDCCH also includes location updates and SMSs. In Fig. 2c, the actual call traffic has some increase compared with the call traffic on Wednesday. From Table I it can be seen that the call traffic increased from a total of 376 Erl on Wednesday to 471 Erl on Thursday, resulting in a total traffic increase of $25\,\%$. Finally, in Fig. 2d, the data traffic allocated to 2G seems higher than the reference day (Wednesday), but this is mostly because the availability of 3G network is also lower than the normal situation, which results in part of the data traffic falling to 2G network. Besides SDCCH seizures, all other KPIs in 2G network have a noticeable increase in the values from Wednesday to Thursday followed by a decrease on Friday.

Correspondingly, Fig. 3 shows the situation in 3G network statistics. First, in Fig. 3a, the amount of circuit-switched (CS) traffic is shown in Erlangs. This amount is slightly higher before and right at the time when the power blackout starts. The amount of CS traffic is reduced after this as the availability of the 3G network degrades, however, the reduction is caused by the lack of service availability, not from the reduced CS traffic behaviour, since the CS traffic increases notably as the availability increases. In Fig. 3b, the amount of downlink (DL) data is shown. A similar effect as in CS traffic is noticeable, i.e. the availability is reducing the data amounts. On the other hand, the traffic amounts are greatly higher before the power blackout starts, most likely due to subscribers trying to search for information about the storm that eventually caused the electricity outage. Fig. 3c shows the number of SMSs in 3G network. The power blackout causes a clear spike in the chart and the amount of SMSs in the entire Thursday evening is clearly higher than in the reference day. Finally, in Fig. 3d, the number of radio access bearers (RABs) has a very noticeable spike at the time when the power blackout started.

C. Example of the capacity increase without random access

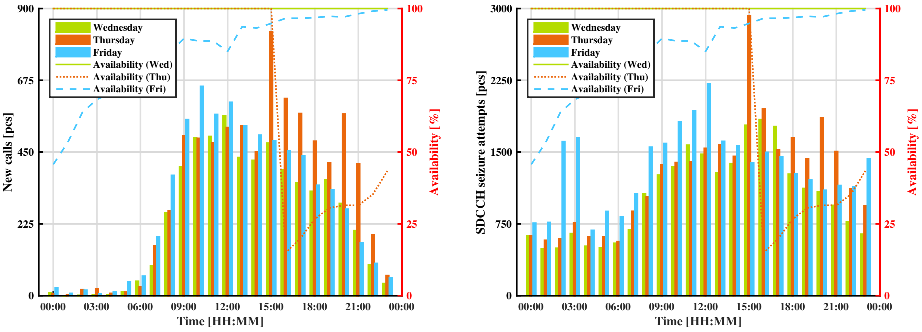
In the smallest GSM configuration case 1 TRX has 7 traffic channels meaning capacity of $2.5\,\mathrm{Erl}$ with $1\,\%$ blocking probability. With the assumption of one call lasting $90\,\mathrm{s}$, which is $25\,\mathrm{mErl}$, this corresponds to having 100 calls in one hour. The difference with regard to $7\,\mathrm{Erl}$ means that the number of calls could be increased theoretically up to 280, i.e. an increase of $180\,\%$ for the number of calls would be achieved. This assumes that there is no blocking because of the idea of preventing the users from calling randomly.

If this idea is applied to the given GSM configuration of the power blackout area, the following increase in the capacity can be noted. The area has 58 TRXs resulting to 464 channels in total, but actually 435 can only be utilized for calls since 29 channels are reserved for signalling purposes (one signaling channel per two TRX). Thus, 435 traffic channels can support roughly $410\,\mathrm{Erl}$ of traffic (16400 calls), whereas theoretically up to $435\,\mathrm{Erl}$ (17400 calls) could be supported. The difference is additional 1000 calls ($6\,\%$) in this configuration.

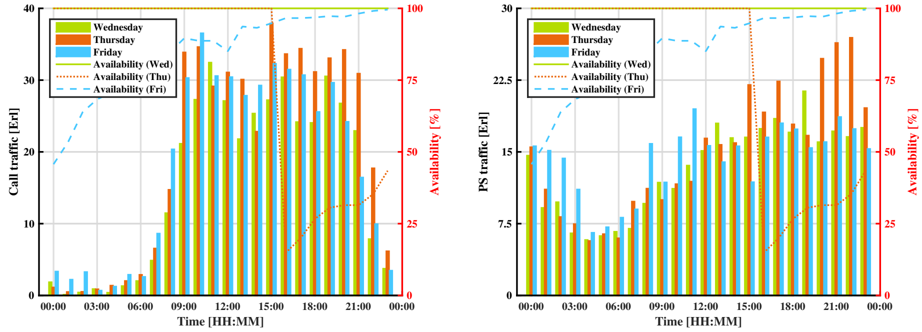
The significant relative difference in the improvement with $1\,\%$ blocking versus the theoretical case in these two examples are caused by lack of overlapping calls, i.e. the capability of calling randomly is removed and perfect call slot allocation is assumed. However, it would be more beneficial to reduce the available capacity in order to save energy to prolong the cellular network service during these electricity network disturbance scenarios. When this idea is combined with the pre-allocation of traffic channels to increase the capacity with no random access, the offered capacity is higher than conventionally and the backup coverage lasts longer.

IV. CONCLUSIONS AND DISCUSSION

This paper provided statistics and analysis from an operational mobile network in Finland. The observed results show how the cellular network subscribers behave in the case of small and uncommon disturbance scenario in the form of electricity network blackout in rural area. The statistics from the GSM and UMTS networks showed how the subscriber *mobile network behavior* changes when it occurred. This behavior can already be noticed before the actual disturbance time, e.g. from the amount of DL data, as the subscribers try to find information related to the possible upcoming disturbance event. When the disturbance (i.e. the power blackout in this case) had finally occurred, especially the call traffic and the amount of SMSs had a noticeable spike in the network statistics. These include an increase of $73\,\%$ in the number of new calls and an increase of $84\,\%$ in the number of SMSs compared with the reference day at the time when the disturbance situation started. The increased service demand trend continued through the majority of the blackout, i.e. despite the lack of cellular network availability the subscribers continued to utilize the network more than usual. It should be noted that the results are based on one disturbance scenario and the reference day for the analysis is also from only one day, thus the generalization of these results would require several other study cases. Nevertheless, this study offers data

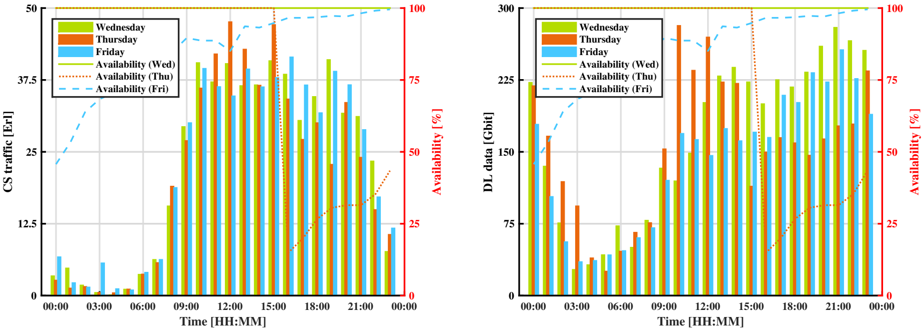


(a) The number of new calls. (b) The number of new SDCCH seizures.

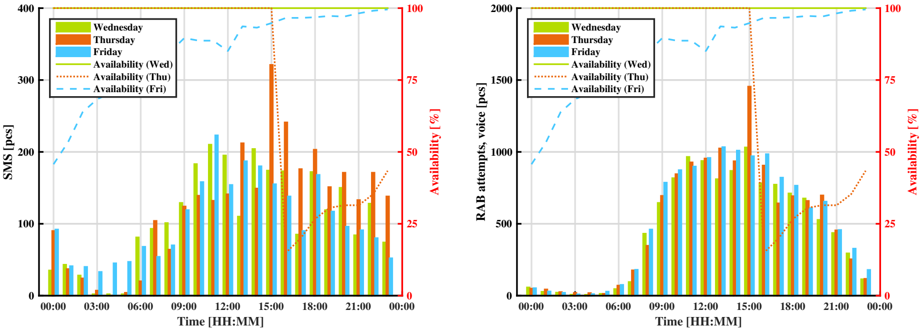


(c) Call traffic in Erl. (d) PS traffic in Erl.

Fig. 2: 2G statistics from the electricity blackout. The time format is 'HH:MM' for a time presentation with two digits for both the hours and minutes.



(a) CS traffic in Erl. (b) The amount of DL data.



(c) The number of SMS. (d) The number of RAB attempts for voice calls.

Fig. 3: 3G statistics from the electricity blackout. The time format is 'HH:MM' for a time presentation with two digits for both the hours and minutes.

TABLE I: 2G and 3G network statistics before, during and after the electricity blackout. The mean and median values present the values for one hour.

	KPI	Wednesday				Thursday				Friday			
		total	*mean*	*median*	*std*	*total*	*mean*	*median*	*std*	*total*	*mean*	*median*	*std*
2G	The number of new calls [pcs]	5787	241	274	199	7652	319	415	254	6794	283	301	228
	The number of new SDCCH seizures [pcs]	25103	1046	1074	450	29890	1245	1380	566	32139	1339	1408	396
	Call traffic [Erl]	376	16	21	12	471	20	26	15	434	18	22	13
	PS traffic [Erl]	319	13	15	5	358	15	16	6	342	14	15	4
3G	CS traffic [Erl]	536	22	30	16	511	21	23	17	543	23	29	16
	The amount of DL data [Gbit]	3958	165	200	84	3714	155	161	72	3429	143	164	70
	The number of SMS [pcs]	2577	107	106	66	2952	123	136	82	2498	104	92	55
	The number of RAB attempts [pcs]	11088	462	482	372	12012	501	548	420	12188	508	535	394

from an operational mobile network operator, and shows how subscribers utilize the network during an uncommon blackout situation.

In order to cope with the lack of mobile network services caused by the outages in the electrical network, some possible solutions were considered. One of these solutions could be partially restricting the ubiquitous cellular network experience, i.e. instead of using the network all the time and everywhere, some limitations for the services might be beneficial from the overall network functionality point of view. These limitations should, however, not prevent the real need in the case of life-threatening emergencies, but instead bring some help to prevent the congestion of cellular networks. A fairly simple solution would include guidelines, i.e. common rules, which would state that if a power blackout should occur, the subscribers should avoid making unnecessary calls and reduce the cellular network utilization in general. This solution, however, is not easy to control since it is only a guideline. Nevertheless, instructions and guidance in advance would increase the probability of unnecessary cellular network utilization. When the capacity requirement could be lowered, some of the cellular network technologies could be shut down immediately to spare more backup energy.

A more complex solution to increase the (speech) capacity during disturbance situations would be to restrict the randomness of the subscribers to access the network. If applied to the configuration of the example network analysis, an increase from $410\,\mathrm{Erl}$ (Erlang-B, $1\,\%$ blocking) to $435\,\mathrm{Erl}$ would be theoretically possible. This would need efficient algorithms to allocate mobile network subscribers to specific time slots to access the network beforehand and to restrict the customers to access the network outside this time slot. Emergency calls should always be prioritized in these situations.

The future work will concentrate on studying how much longer mobile networks could operate in the case of disturbance scenarios while operating on backup power *and* applying some energy saving prospects. These include instructions and guidelines for the subscribers on how to utilize the network during disturbance scenarios. This in itself is an interesting research topic: how would this kind of preparedness affect the subscriber behaviour. It would enable a higher success rate on completed calls as the congestion would be much lower than in current solutions and enable more capacity, i.e. the available resources would be utilized more efficiently during these events. This should also lead to being able to operate on more restricted configuration resulting in more energy savings and prolonging the backup coverage time.

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