User Behaviour in the Context of Quality of Experience in Realistic Mobile Radio Networks

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Abstract— Simulating mobile radio networks with individual users typically involves traffic models. Traffic models can be fairly simple, e.g. Constant Bit Rate (CBR), or rather complex, e.g. multiple service types in combination with arrival processes. Regardless of the level of detail of such traffic models none of them considers the case that a user terminates a session simply because of a too bad experience. But particularly when accounting for Quality of Service (QoS) or Quality of Experience (QoE) indicators, it might not be sufficient to simply compare the required data rate with the data rate the mobile radio system offers. In order to tackle such problems, a new model describing the users' "patience time" is introduced in this document. It computes the time the individual user is willing to wait for better (radio) conditions based on the respective service. Once this time is expired, the service is terminated – with a bad experience for one user, but the side effect that more resources are available for other users in the system. Applying this model, simulations of mobile radio systems are brought to a more realistic level.

Keywords— quality of service; QoS; quality of experience; QoE; patience time; user behaviour; service model; traffic model; user satisfaction; realistic network;

I. INTRODUCTION

Today's mobile radio networks offer a multitude of services, like Constant Bit Rate (CBR) traffic types, such as voice calls, Variable Bit Rate (VBR) traffic types, like audio and video streaming, Packet Traffic types (PT), like FTP download, web and messaging services. In order to simulate these networks with individual users it is crucial to consider the different characteristics of the services as well. On the one hand PT sessions will lead to spikes in the cell load. This is due to the users that require the maximum available data rate in order to finish the session as fast as possible. On the other hand, typical CBR sessions require data rates that are lower (e.g. on 13 kbps for a voice call [1]) but over a longer time, which leads to a continuous, and more moderate cell resource utilisation. However, only a combination of both service types will result in realistic cell load behaviour as presented in Figure 1.

It can be seen that the cell load is at 100 % for certain periods of time, meaning that the user requirements lead to a full utilisation of resources. In the meanwhile, the resource utilisation drops at only 10%[1] or slightly above. The dashed line in the plot is indicating the mean cell load for a period of 15 minutes, which is at around 20 %. It illustrates the high temporal variation, which can be observed by considering this bursty traffic.

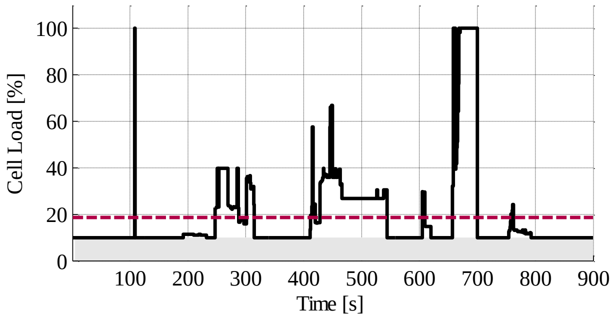

Figure 1: Simulated cell utilisation over a time interval of 15 minutes

The consequence of this behaviour for the individual user in terms of Quality of Experience (QoE) can be extreme. Given a user currently consumes a HD video streaming session, which has a rather constant data rate request. If this is the only session in the cell, the user will be most likely fully satisfied because a common mobile radio system such as UMTS or LTE should be capable of delivering the required (rather high) data rate. Now, assuming a second user starts a session, but this time a FTP download, so the maximum possible data rate is requested and delivered by the system. This will lead to a fully loaded cell. Depending on the resource allocation the first user, which requires a rather high data rate, might not get the desired data rate. The assumption now is that in reality this user will bear such (bad) conditions for a while. If the conditions will not get better, the user will terminate the session.

To model such user behaviour, this paper introduces a User Patience Time Model (UPTM) which anticipates the human intervention and thus brings system-level simulations of mobile radio communication a step closer to realistic behaviour. The UPTM differentiates the currently active session. Based on the session the user satisfaction is calculated and mapped to a maximum time the user is willing to tolerate such bad condition until the session would be terminated.

The remainder of this paper is structured as follows: First, related work is presented in Section II. The actual Patience Time Model (PTM) is explained in detail in Section III. Nu-

[1] To account for pilots and signalling traffic, a minimum cell load of 10 % is assumed

merical results based on a realistic scenario setup are given in Section IV. And last but not least, Section **Error! Reference source not found.** provides a conclusion of the findings.

II. Related Work

A few authors have dealt with the subject of user experience the way it is interpreted herein. The authors of [2] investigated the congestion at flow level and the impact of user behaviour in a theoretical setup. Results have shown that if user behaviour is considered, the system congestion is stable due to user impatience. In [3] real measurements have been taken into account to explore whether a worse network performance leads to impatience of the users consuming a web session service. A main conclusion is that the probably of aborting sessions is increasing when the user throughputs are low. However, to the authors' best knowledge, no modelling of users actively aborting their sessions in a realistic radio network scenario with a multitude of services has been made. Neither has it been investigated, yet.

III. User Patience and Quality of Experience

In this Section the proposed UPTM is described in detail. At first, Subsection A elaborates on so-called *Satisfaction Indicators* which are crucial for the latter definition of *Patience Time Curves*, which will be introduced in Subsection B. The actual consecutive steps that are needed for modelling user patience will be presented in Subsection C.

A. Satisfaction Indicator

In order to get a proper input for the actual user patience time modelling, a metric has to be defined that stands for the satisfaction level of the user consuming a particular service. Herein, the understanding of satisfaction is that a user gets the desired data rate or throughput, so that the respective service is operating as it should. For this purpose, the following rather simple method has been chosen, which uses the requested data rate, defined by the service itself, and the offered data rate, which is the data rate the system is able to provide the user with. By dividing the offered by the requested data rate, a value between zero and infinity will be acquired.

$$Satisfaction\ Indicator\ (SI) = \frac{Data\ rate_{offered}}{Data\ rate_{expected}} \cdot 100\ [\%]$$

If the value is greater than or equal to 100 % the user is fully satisfied. If the value is less than one, the user is unsatisfied. Unsatisfied means, the service is not working as fast or with the quality the user expects. For example, an HD video stream gets interrupted or the latency is high.

For CBR traffic types, the above mentioned method is easily applicable. In case of a PT session type, the requested data rate is infinite and hence the SI would be 0. To overcome this, an expected data rate is introduced which is equivalent for the requested data rate of a CBR session. This expected data rate is depending on the actual PT service and on the downlink speed of the system. The motivation for the latter is the assumption that a user is more tolerant to lower data rates in earlier mobile radios systems, such as GSM/EDGE, compared to current technologies, like UMTS/HSDPA+ or LTE. An example for the herein considered FB services and expected download speeds can be found in Table 1.

Packet traffic service	**Data rate expectations [kbps]**		
	Slow	Medium	Fast
Messaging	5	50	250
Web session	10	100	200
FTP download	100	500	2000

Table 1: Data rate expectations for different session types and technology capabilities

Other possibilities to derive a SI can be applied as well.

B. Patience Time Curves

The assumption in this paper is that the user patience mainly depends on the current service. A voice call is naturally associated with a very low tolerance to bad quality and thus a user is unsatisfied after a rather short amount of time. This has to be reflected in the patience time as well as the general tolerance towards lower data rates for FTP downloads. Such downloads might be running as background task and thus the tolerance for a slow download is higher.

This user patience behaviour is captured by so called User Patience Time Curves (UPTCs). A UPTC here is defined per service with only two parameters and can be expressed by the following function:

$$f(T_{Max}, \alpha, SI) = \begin{cases} T_{Max} \cdot e^{-\alpha(100-SI)} & SI < 100\ \% \\ \infty & SI\ \geq 100\ \% \end{cases}$$

The first parameter (T_{Max}) is defining the maximum time a user is willing to wait, if the user is just slightly unsatisfied. E.g. for voice this time is rather short (60 seconds) and for FTP download rather long (10 minutes). The second parameter (α) is defining the shape of the UPTC. A value close to zero leads to a rather steep curve, whereas higher values lead to a flat curve. The third parameter is the current user Satisfaction Indicator (SI), as explained in Section III.A.

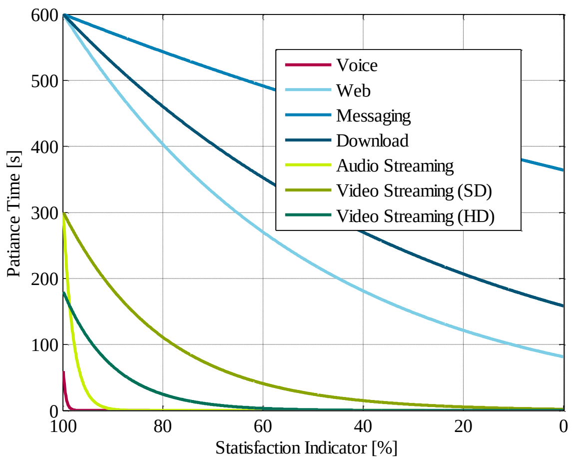

Figure 2: Patience Time Curves (UPTCs) for different service types

Exemplary values, which have been chosen to reflect the service type characteristics, can be found in **Error! Reference source not found.** and a visualisation of the resulting curves is shown in Figure 1.

Traffic Name	T_{max} [seconds]	Shaping factor α
Voice	60	0.5
Audio streaming	300	2
Video streaming (SD)	300	20
Video streaming (HD)	180	10
Messaging	600	50
Web session	600	200
FTP download	600	75

Table 2: Patience time model parameters T_{max} and α for different service types

C. Modelling of User Patience

The actual modelling of user patience is subdivided into different steps and takes the above mentioned indicators into account. First of all, the SI for all users with an active session has to be calculated. With the current values the two main parameters (T_{max} and α) can be looked up and the PT can be calculated. In addition a filtering function is used for patience time values in order to smooth the results and to neglect outliers. Such function might be characterised by a factor β that accounts for a weighting of old values.

$$\widehat{PT}_t = \beta \cdot \widehat{PT}_{t-1} + (1 - \beta) \cdot PT_t$$

Where PT_t denotes the new measured value, $\widehat{PT}_{t-1}$ the old and $\widehat{PT}_t$ the new filtered value, respectively. An exemplary value for β is 0.75, which gives the old values a higher weight.

In the following two cases have to be considered. In one case the SI is below 100 % and in the other SI is greater or equal 100 %. Regardless of the two cases a User Waiting Time (UWT) of the user will be considered. This waiting time accounts for the amount of time the user has suffered from not fully QoE, i.e. a SI below 100 %.

a) A user is active and the SI is less than 100 %. Thus, the user is unsatisfied and the waiting time counter is increased by value σ. Note that in a simulation this added value could represent the time resolution of the simulation itself. If UWT exceeds the calculated patience time the user terminates the session because the quality of experience is simply too bad.

b) A user is active and the SI is greater than or equal to 100 %, so the user is fully satisfied. If UWT is greater than 0, because the user was unsatisfied before, UWT gets decreased by value υ. Such value might be the same as for the increasing or a higher one to account for a faster relaxation.

The procedure of actively dropping a traffic session is depicted in **Error! Reference source not found.**. The red line is showing the user satisfaction calculated as previously proposed in Subsection A. The blue line indicates at what point this specific user decides to terminate the session due to a too bad QoE. It is clearly visible that the satisfaction starts declining at around 3 seconds until 8 seconds. At that point, the patience time is over and the user drops the session. Consequently the user is inactive und thus do not feature a satisfaction.

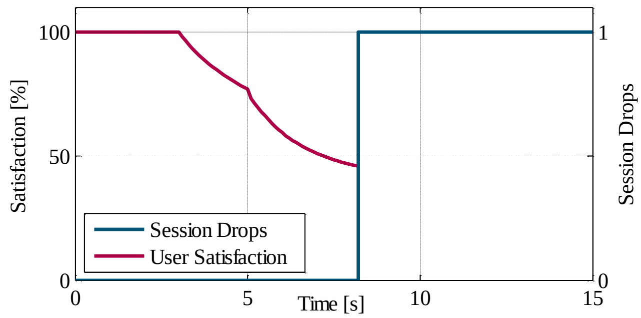

Figure 3: Dependency of the user satisfaction and the decision to drop an active traffic session due to impatience of the user

The different steps for modelling the user patience are visualised in a flow chart in Figure 4.

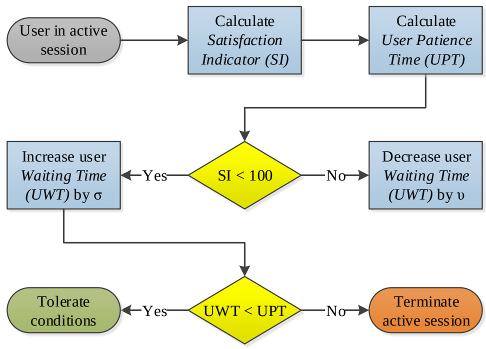

Figure 4: Flow chart of the modelling of User Patience Time (UPT)

IV. Simulation Approach and Recent Results

In order to analyse the effects of the user patience time model a realistic scenario defined in [4] has been considered. An area of 3 km by 5 km in the city centre of Hannover, Germany has been chosen. As mobile radio network a LTE network at 1800 MHz with a given bandwidth of 10 MHz has been considered. To account for individual and realistic users indoor users [5], pedestrian [6] and vehicular users [7] have been generated. Finally around 500 users were placed in the simulation scenario and simulated for a time period of 10 minutes. The temporal resolution was set to 100 ms, leading to 6000 simulation steps in total. The used simulator has been described in details in [8].

Service Name	Traffic type	Data rate requirements	Fraction of usage
Voice	CBR	13,3 kbps	10 %
Audio streaming	CBR	200 kbps	50 %
Messaging	PT	100 kb	5 %
Web session	PT	According to [9]	15 %
FTP download	PT	According to [9]	20 %

Table 3: Service type specifications

In this paper different types of services were derived on the basis of [10] and [1]. The traffic types, data rate requirements and the fraction of usage in the system are presented in Table 3. For reasons of simplicity it is assumed that a new session is spawned based on a Poisson process with a rate of 2 minutes. The session durations for the two CBR services were derived by an exponential distribution with the mean of 1 minute.

The following sections will elaborate on three Key Performance Indications (KPIs): The mean network utilisation, the amount of active session and the user satisfaction. The results for the respective KPIs will be presented for three different traffic scaling factors (1, 100 and 200). Such factors have been used in the simulation to multiply the requested traffic of the users. The original data rate has been used if the factor was set to one. The data rate was 100 or 200 times greater as the original if the factor was set accordingly.

A. (Mean) Network utilisation

At first the different mean network resource utilisation is compared. Figure 5 show the results without the proposed the UPTM. Here it can be observed that the original traffic requests (i.e. with a scaling of one) leads to an almost unutilised mobile network. The utilisation is only around ten and 20 %. By increasing the scaling factor a higher utilisation can be observed.

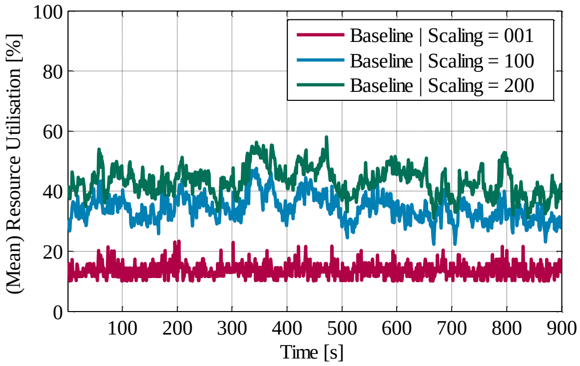

Figure 5: (Mean) resource utilisation *without* the use of the UPTM

Figure 6 shows the results with the UPTM. Noticeable is the lower mean network utilisation for the higher scaling factors. The reason for that will become clearer in the following elaborations when discussing the user satisfaction and the amount of active sessions.

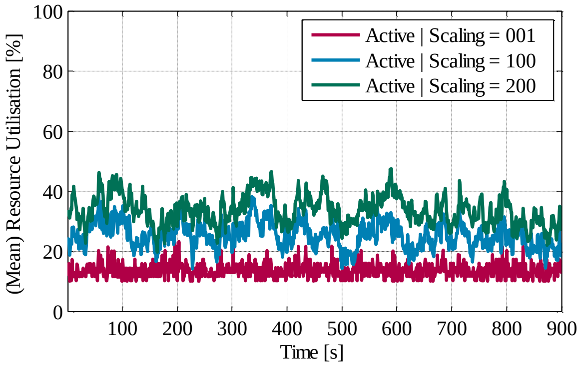

Figure 6: (Mean) resource utilisation *with* the use of the UPTM

B. Simultaneously active session in the network

Figure 7 and Figure 8 illustrate the amount of simultaneous active sessions over time in the network. The generated sessions, generated with the parameters mentions in Table 3, are equal for each simulation run. Nevertheless the amounts of sessions are not the same for different scaling factors. This is due to the fact that not only CBR traffic sessions are available, but also PT sessions. The FTP download sessions naturally have a bigger file size and need longer time to finish.

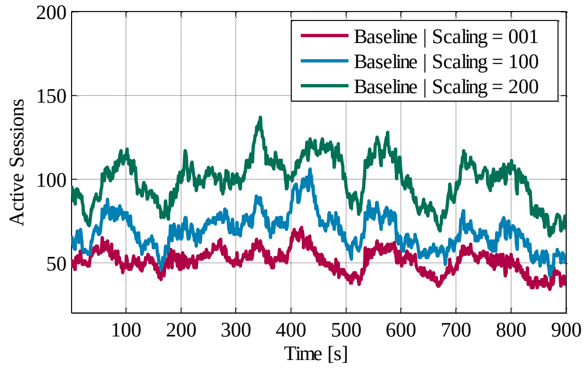

Figure 7: Active session without the use of the UPTM

If the UPTM is active, user can decide to terminate dedicated session and thus the overall amount is lower compared to the baseline. It is also observable that the amounts of active sessions seem to converge towards an equal amount of sessions.

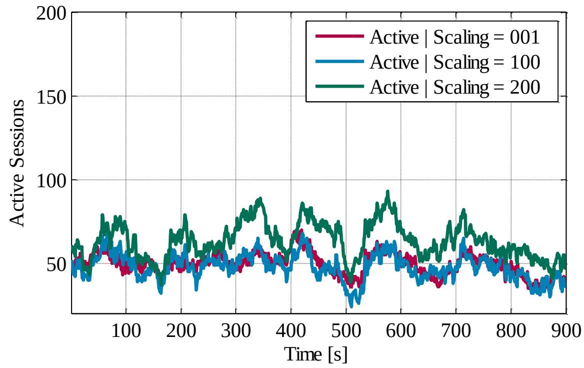

Figure 8: Active sessions without the use of the UPTM

C. (Mean) User satisfaction

The last performance indicator, namely the (mean) user satisfaction in the mobile network is presented in Figure 9 and Figure 10. The overall satisfaction decreases by increasing the scaling factor and thus the overall traffic request for the network. This is obvious since a higher request will lead to a higher resource utilisation and hence to a higher probability of not receiving the desired data rate.

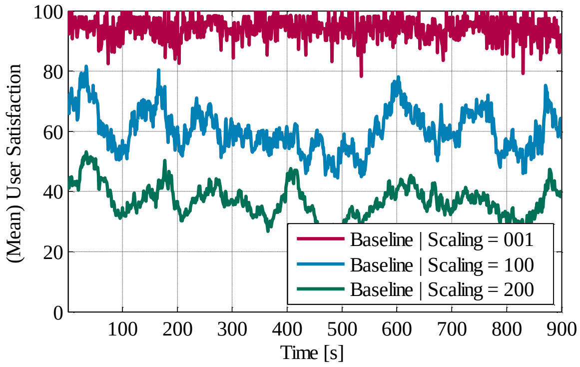

Figure 9: User satisfaction without the use of the UPTM

With the UPTM the satisfaction in the network is higher. But this comes, as shown in Subsection B, with an overall lower amount of active sessions in the network, i.e. higher amount of session drops. In other words, some users terminated the session which led to freed-up resources that could be used by the remaining active users in the system.

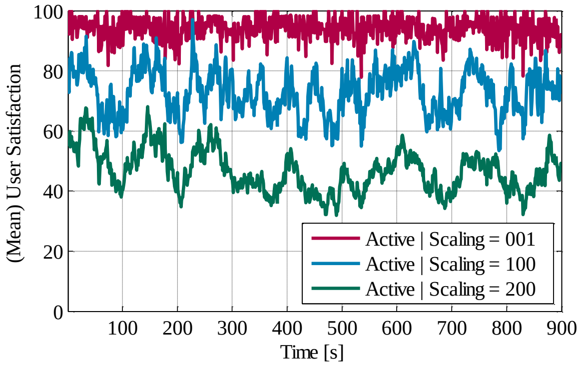

Figure 10: User satisfaction without the use of the UPTM

V. Conclusion and Future Work

In this paper a new model has been introduced that takes the user patience into account to address QoS and QoE aspects. Patience here means that a certain data rate for specific types of services, and thus a minimum amount of quality, needs to be fulfilled so that the user is satisfied with the experience. Otherwise the conditions are tolerated for a certain amount of time (i.e. patience) until the service gets actively terminated.

Results have shown that this User Patience Time Model (UPTM) leads to a higher overall user satisfaction in the network. But this higher satisfaction comes with the cost of a higher amount of dropped session.

Future work will include the investigation of Self-Organizing Network functionality in cooperation with this proposed model, the verification of parameters based on experimental results and the inclusion of more precise service classes such as packed based web surfing.

In addition to that, an interaction of the user behaviour with the creation of upcoming sessions is foreseen, i.e. if a user was unsatisfied and dropped a session, a future session will be postponed because of the bad QoE in the past.

Acknowledgment

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