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A TESTBED FOR THE EVALUATION OF QOS PROVISIONING IN WCDMA BASED 3G WIRELESS NETWORKS

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Abstract

This paper presents the design patterns and architecture of a testbed for the evaluation of Quality of Service (QoS) provisioning in WCDMA (Wideband Code Division Multiple Access) based third generation wireless networks. The testbed allows for the evaluation of QoS adaptation techniques that supercedes to the traditional power control in the Radio Resource Manager (RRM); it handles classes of service defined for the Universal Mobile Telecommunication System (UMTS), as well as mobility and handoffs. The main focus of this paper is the testbed itself, the underlying assumptions including those related to the physical layer, the user defined parameters, and the various measurements and ratios gathered for the evaluation of QoS provisioning strategies. The testbed has been used to evaluate the performance of QoS adaptation algorithms under a variety of admission strategies and load scenarios. The performance results of these QoS adaptation strategies will be given in a separate paper.

Keywords: UMTS, WCDMA Power control, CAC, QoS Adaptation

1. Introduction

Recent advances in wireless technology have given rise to a 3G technology called Universal Mobile Telecommunication System (UMTS). This new system is expected to be effective in delivering multimedia services including: audio, video, voice, and data services, which can be accessed any time and anywhere in the world through fixed, wireless, and satellite systems. It is expected that this system will be able to deliver broadband information with up to 2 Mbps per mobile user [1-3].

These multimedia services are characterized by stringent real time requirements, great sensitivity to delivery delay and packet loss; and a need for a considerable amount of bandwidth. It was therefore important to support QoS provisioning in UMTS infrastructure. For this reason, the 3rd Generation Partnership Project (3GPP) has proposed four main categories of services that need to be provided in UMTS on an end-to-end basis [4]:

- Real time (RT) classes: Conversational and Streaming.
- Non Real Time (NRT) classes: Interactive and Background.

Table 1 summarizes the main characteristics of these classes, each of which imposes different QoS requirements on the UMTS network, which must be maintained during the lifetime of the corresponding connections.

Furthermore, Wideband Code Division Multiple Access (WCDMA) has emerged as the multiple access solution for the UTRAN (Universal Terrestrial Radio Access Network) component of UMTS. It was chosen as the radio transmission technology for UMTS by the European Telecommunications Standard Institute (ETSI) [5].

Class Name	Description and Usage
Conversational (Class 1 [1])	• Conservative real-time. • No ARQ (retransmission). • High sensitivity to delay and jitter. • Video Conferencing/VoIP.
Streaming (Class 2)	• Streaming real-time. • No ARQ. • High sensitivity to jitter. • Medium sensitivity to delay. • Audio/Video Retrieval.
Interactive (Class 3)	• Interactive best effort. • ARQ (RLC level). • High sensitivity to round trip delay time and Bit Error Rate (BER). • Low sensitivity to delay. • WWW/Database Retrieval.
Background (Class 4)	• Background best effort • ARQ (RLC level). • High sensitivity to BER. • No delay sensitivity. • Email/File Transfer.

Table 1. UMTS Traffic Classes

Unlike in wired links such as ATM [6], provisioning QoS over WCDMA air interface cannot be fulfilled by proper Admission Control [7] and efficient Scheduling [8] only. This is mainly due to the inherent characteristics of the wireless link, namely: user mobility and fading channel

[1] Throughout the paper, we will be referring to these classes by their respective numbers.

(time variation) [9-11], unexpected Soft Handoffs (SHOs), high error rates, inherent interference limited characteristics of WCDMA [5], and low and varying bandwidth (2 Mbps at most).

For this reason, QoS Adaptation [12-14] has emerged as a key feature in QoS provisioning in WCDMA based 3G wireless networks. QoS adaptation aims at maintaining QoS requirements of certain connection types, as well as achieving high system utilization, by *degrading* the QoS contract of connections willing to do so [15] in order to meet requirements of other connections such as SHO requests. This of course assumes that at the establishment of a connection, users[2] provide the base/wireless network with indications as to their willingness to be degraded, and the extent to which they are willing to do so. A framework for this, which we adopted in our testbed, has been presented in [15]. This framework uses a patented QoS parameter termed the Service Degradation Descriptor (SDD). The higher this QoS parameter is, the more a user is willing to be degraded, and the less the user is charged. A typical video telephony service can be degraded/adapted to current network conditions by using a color/grey scale degradation or by lowering the quality of coded speech. Of course, for certain types of traffic SDD could be fixed the network.

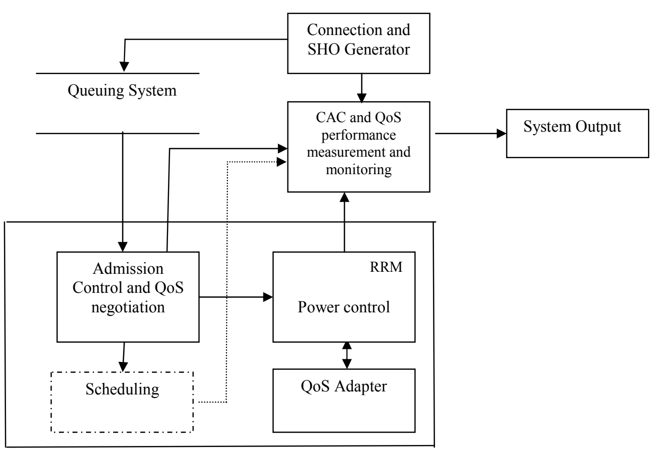

Fig. 1. General Architecture of the QoS Adaptation Testbed. Power control module with the help of the QoS adapter supercedes to the traditional closed loop control performed by RRM

This paper presents the design patterns and the architecture of a testbed for the evaluation of QoS provisioning in WCDMA based 3G wireless networks. In particular, this testbed is intended for investigating the effects of incorporating a QoS Adaptation scheme that supercedes to the traditional RRM in QoS-enabled 3G networks such as UMTS. It also presents all system underlying assumptions and user controlled parameters, as well as the various measurements and ratios collected to evaluate the performance of QoS adaptation strategies. The paper does not discuss the results obtained for particular strategies; these will be published separately.

The rest of the paper is structured as follows. Section 2 describes the testbed architecture. Section 3 is concerned with the underlying assumptions of the testbed. Section 4 presents the internals of the testbed. Section 5 presents the output of the testbed. Section 6 presents the criteria for evaluating QoS adaptation strategies.

2. Testbed Architecture

The different building blocks of the testbed can be divided into six (6) modules (see Fig. 1) out of which five (5) are of direct interest:

2.1. Connection Generator Module

This module generates new connections according to user specified arrival patterns (UAPs). The Exponential distribution is available to model the arrivals within a cell. Each user is represented by his/her QoS profile and system attributes. The QoS profile contains the following attributes: traffic class, bandwidth, Service Description Descriptor (SDD), user speed, dwelling time (indicating the duration of the connection/call in the cell), and timeout (indicating the duration of the connection request in the queuing system before abandon). Upon generation, each connection is randomly assigned a traffic class (1-4), an SDD (0-5), which remains constant throughout its lifetime, and a bandwidth. The latter is chosen to represent bit rate requirements for various types of applications such as telephony, video telephony, video on demand, and traditional data services (see Table 1). Table 2 shows Bandwidth requirements associated with each class of service, which are assigned to connections by default in the current implementation of the testbed.

Connection Class	Bandwidth
1	16Kbps, 64Kbps, 144Kbps, 384Kbps
2	2Mbps, 384Kbps
3	16Kbps, 64Kbps, 144Kbps
4	16Kbps, 64Kbps

Table 2. Bandwidth requirements for each class of service

Together with these, a connection is assigned a mobility speed. This assignment is dependent on both class and bandwidth (see section 3.3). A predefined percentage of generated requests are marked as SHO requests from neighboring cells. SHO requests are processed differently than new connection requests. Fig. 3 explicates the full SHO handling process, in which a SHO request must be granted at the expense of degrading the QoS of other live connections, and eventually dropping some of them. This is not the case for new connection requests (see Fig 2) for which no dropping of other users is allowed. All connections generated are queued using an unbounded buffer.

[2] User, subscriber, and connection are used interchangeably, hereafter.

2.2. Admission Controller Module (CAC)

This module services connections from the Queuing System with a First in First out (FIFO) policy. It makes its decision to whether to accept or reject the user's request based solely on his/her QoS profile and the maximum available power[3] in the system P_{max}. The system state is updated accordingly. Various admission strategies are available:

Strict admission strategy:
In this strategy, a connection *new* is accepted in the system at instant t only if $\sum P_i\ (t) + P_{new} \leq P_{max}$, where $P_i(t)$ is the power required by existing connection i, and P_{new} is the power required by connection *new.*

NRT Overload admission strategy:
In this strategy the base/system is allowed to accept connections even if the total power required by all connections exceeds the available power. In this case NRT connections will have to be delayed by the scheduler. Specifically, a connection *new* is accepted in the system at instant t if and only if both conditions hold:

$\sum P_{i/RT}\ (t) \leq P_{max}$ where $P_{i/RT}\ (t)$ is the power required by existing real time connection i, (that is class 1 and 2 connections in the system including eventually the new connection).

and

$\sum P_i(t) \leq (1+\alpha)\ P_{max}$, where $0<\alpha<1$ indicates the maximum overload allowed for NRT connections, and i spans across all existing connections including the one under admission decision.

Fig. 2 shows the New Connection (NC) Admission handling process. A NC is queued first. If the system is stable, the NC is considered for admission. Otherwise, it will remain in the queuing system. A queued connection can be dropped from the queue if it reaches its timeout (set to 2 unit time by default) or if it terminates or moves to another cell. Fig 2 also shows that negotiation of QoS requirements (for the time being bandwidth only) takes place in the Admission Controller entity, for *a would be* rejected NC during its stay in the queuing system. Furthermore, if negotiation option is no more possible and a NRT admission strategy is chosen as an admission strategy, the NC can be accepted if it belongs to a NRT class, and reconsidered later when power will allow so. Fig. 3 shows the Soft Handoff (SHO) Admission handling process. A SHO undertake the same process as an NC. However, unlike an NC, the negotiation option is no longer possible, and QoS Adaptation is triggered to provide the SHO with the necessary bandwidth at the expense of the existing connections. Furthermore, if QoS adaptation option is no more possible and a NRT admission strategy is chosen as an admission strategy, the SHO can be accepted if it belongs to a NRT class, and reconsidered when power will allow so.

2.3. Power Control Module

Each active connection (i) experiences a continuous update of its cost C_i (t) (see eq. (1) in section 3.1) and power P_i (t) (see eq. (2) in section 3.1) given that its channel gain H_i (t), interference I_i (t), and position X_i (t) change over time.
We assume the base/system implements closed loop power control at the level of a Radio Resource Manager (RRM) on which the QoS adaptation strategies are trying to improve. In taking into account QoS as an extra parameter for adaptation, we supercede to the basic closed loop control in RRM. Indeed RRM only takes into account channel gain when making a decision to control base transmit power. The QoS based adaptation, however, takes into consideration not only channel gain, but also QoS requirements of existing users, namely the bit rate and the willingness to be degraded SDD.

2.4. QoS Adapter Module

When, due to the problems discussed in the introduction, congestion occurs (see section 3.2 for details), the QoS Adaptation entity is triggered to address the overload in power requirements. It is this entity that is of concern to us, and that we want to evaluate using our testbed. Such entity copes with the link degradation in WCDMA based 3G wireless networks, by acting on using QoS profiles of the active mobile users.
Unlike traditional power control mechanisms which do not take into account user QoS profile while taking decision in face of congestion, the adaptation algorithms we would like to evaluate use the negotiated profile for accepted connections to resolve congestion, effectively superceding to the classical closed loop power control in CDMA systems.

2.5. CAC and QoS Adaptation performance measurement and monitoring

This entity periodically samples and records the system state. Several performance measurements and ratios are recorded/ computed (see section 5). These are pushed through the system output module for real time display.

3. Assumptions

The testbed is built with a series of underlying assumptions. These must be considered when drawing conclusions of experimental results. All underlying assumptions have been categorized and summarized below:

3.1. Physical Layer Assumptions

- Power is considered to be the only limiting resource. Other system resource such as spreading codes [11] and buffering capacity are considered to be available in sufficient quantities. P_{max} is set to 35W for hundred

[3] Other system resources such as spreading sequences and buffers are assumed to exist in sufficient numbers/quantities.

users; and the Cost threshold (CT) is set to 2.5 mW/bit. CT indicates which connections are consuming too much power per bit. Of course these can be dynamically set to otherwise, using the provided sliders in the GUI-based control window.

- The cost of a connection (i) at a given time is computed according to the following formula [16]:

$$C_i(t) = \frac{Eb}{No} \cdot \frac{1}{W} \cdot \frac{I_i(t)}{H_i(t)} \qquad (1)$$

- Energy to Noise ratio Eb/No is set by default to 18dB. It can also be set to a different value using the provided GUI to account for quality of User equipment.
- Intercell interference is not taken into consideration in the current version of the testbed.
- The Chip rate (W) is set to 3.84 Mchips. (The end-user can change this too, using the provided GUI).
- The interference at a given time I_i (t) is the sum of interferences exerted by existing users on the target user at a given time within the same cell. The central limit theorem is used to model I_i (t) as a Gaussian process with zero mean and a given variance σ^2 [9]. The σ^2 was initially set to 0.5. However, it can be set to otherwise to account for multi-path.
- The channel gain at a given time H_i (t) follows a Rayleigh distribution. This is modeled using a random process in the frequency domain [9].
- The power required to provide the bit rate R_i for a connection (i) at a given time t is computed according to the following formula [16]:

$$P_i(t) = C_i(t) * R_i(t) \qquad (2)$$

where Ci(t) is the current cost of the connection.

3.2. System and Resource Assumptions

- For simplicity reasons, each user is allowed to request one connection at time. Additionally, we assume that QoS parameters delay and Bit Error Rate (BER) constraints are handled by other system components, namely the scheduler, and the coding scheme used. The scheduler is assumed to operate close to optimum in meeting all delay requirements.
- The dwelling time of a connection is set according to its bandwidth and class: 60min for 2Mbps (corresponding to a one hour video on demand stream), 30 min for 384kbps (corresponding to a videophone call), 30 min for 144kbps, 4 min for 64kbps and 16kbps (corresponding to a typical voice call). Of course these can be set to different values using the GUI provided for the testbed.

  Congestion is triggered after a congestion indication persists for a predefined duration (set to two unit times by default). Congestion is indicated at instant t if $\sum P_i(t) > P_{max}$ where P_i (t) is the power required by connection i.

3.3. User Motion Assumptions

A user position at a given time X_i (t) changes over time according to the speed assigned to the corresponding connection. The speed of each connection is set according to its bandwidth, that is, (0km/h for 2Mbps, 60km/h for 384kbps, 100km/h for 144kbps, 120km/h for 64kbps, and 160km/h for 16kbps). Users are assumed to move with a constant velocity V_i(t). Any user exceeding the range of the cell is considered out of range, and is dropped. The various speeds assigned to connections can also be set to different value using the provided GUI for the testbed.

4. Internals of the Testbed

The following section describes the internal iterative process within the testbed. First, the system is initiated with 100 user defined connections of different QoS profiles to bring it to a steady state. Then, each iteration of the process performs the following computations in one unit time:

- Sample active users' QoS profiles, their positions, and various other system variables.
- Run the Connection Generator to generate a random number of new connections according to the chosen users' arrival pattern and insert them into the queuing system.
- Update active users non static parameters: position, cost, and power.
- In case of congestion, trigger the QoS adapter to address the overload problem.
- Run the Admission Controller to attempt to accept the connections waiting in the queuing system.

This process is iterated until the simulation, is stopped.

5. Output of the Testbed

To evaluate the performance of QoS Adaptation strategies embedded into the system, measurements and system variables sampled are used to display various graphs in real time. Fig. 4 shows the Cost versus Time, the Interference versus Time, and the Channel Gain versus Time graphs of a selected active connection. Fig. 5 shows the number of RT connections versus Time, the number of NRT connections versus Time, and the total number of connections versus Time graphs. Additionally, it displays the total power required for RT and NRT connections versus Time graphs, as well as the graph for the total power required for all connections within the system. Congestion and NRT overload are clearly labeled. Furthermore, the following ratios are computed:

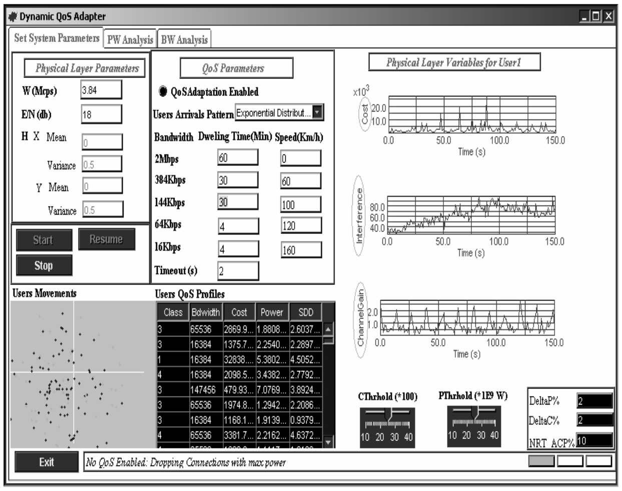

Fig. 4. Testbed main panel. Left: system and QoS parameter controls, users positions in the cell, and users QoS profiles. Right: (1) the Cost vs time, (2) The Interference vs time, and (3) the Channel Gain vs time graphs of a selected mobile user.

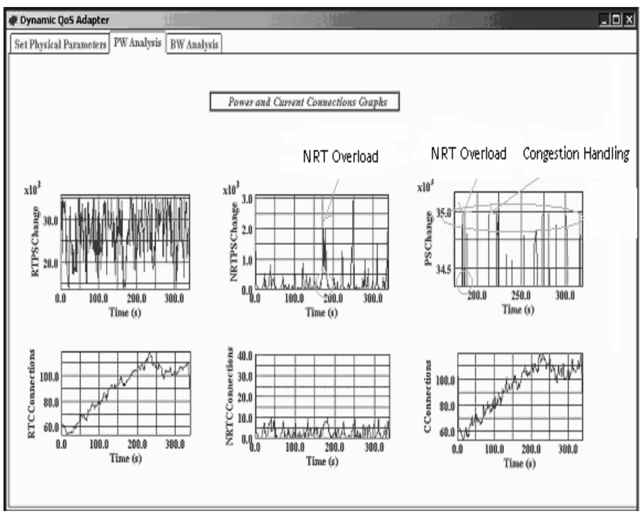

Fig. 5. From top down and left to right, (1) The Power required for RT connections vs Time, (2) the Power required for NRT connections vs Time, (3) the Total Power required for all connections in the system vs Time, (4) The number of RT connections vs Time, (5) the number of NRT connections vs Time, and (6) the total number of connections vs Time

-**Real Time Dropping Ratio:** the # of real time dropped connections/Total # of dropped connections.

-**Non Real Time Dropping Ratio:** the # of non real time dropped connections/Total # of dropped connections.

-**Real Time Active Ratio:** the # of real time active connections/Total # of active connections.

-Non Real Time Active Ratio: the # of non real time active connections/Total # of active connections.

-Acceptance Ratio: the # of accepted connections/ Total # of connections considered by the CAC.

-Rejection Ratio: the # of rejected connections/Total # of connections considered by the CAC.

6. Evaluation of QoS Adaptation algorithms

The testbed has been used to measure the performance of two QoS provisioning strategies under a variety of CAC and congestion strategies and load scenarios, and the results of this comparison will appear in a separate paper. The performance of a strategy is linked directly to its ability to reconcile the conflicting objectives: maximizing the network provider earnings on the one hand (bandwidth utilization, especially RT bandwidth) and minimizing user blocking including handoffs on the other and.

7. Conclusion and Future Work

We have presented a testbed for the evaluation of QoS adaptation in WCDMA based 3G Wireless Networks. We have described and motivated all its building blocks, and given all underlying assumptions and system parameters. We have also presented sample output of the testbed. Our current efforts are directed towards building support for a distributed CAC in the testbed, and the evaluation of various adaptation strategies.

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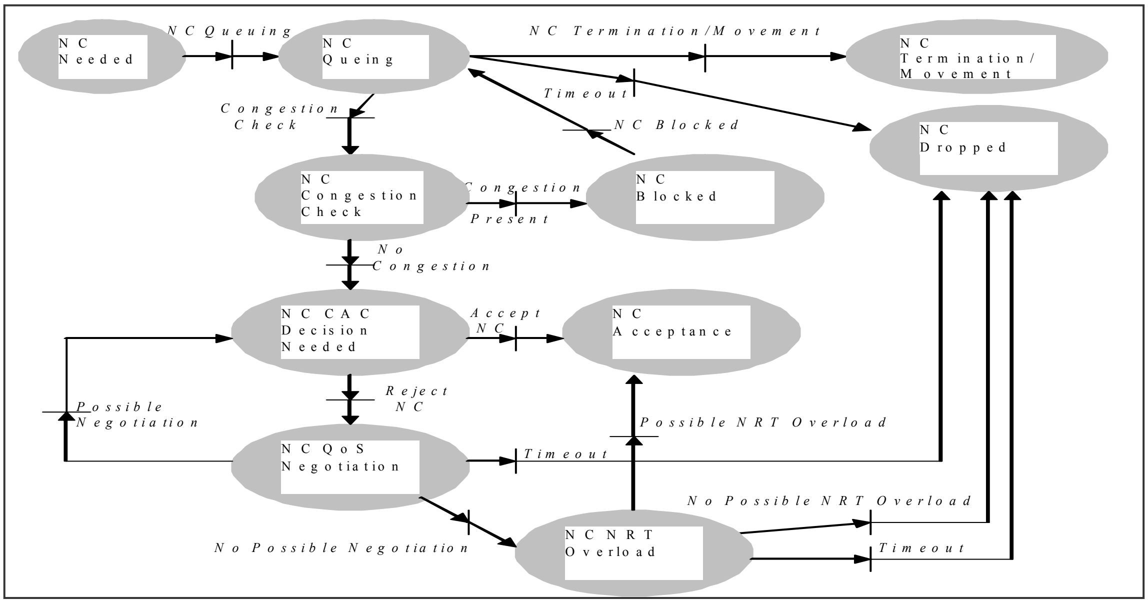

Fig. 2. New Connection Admission Process

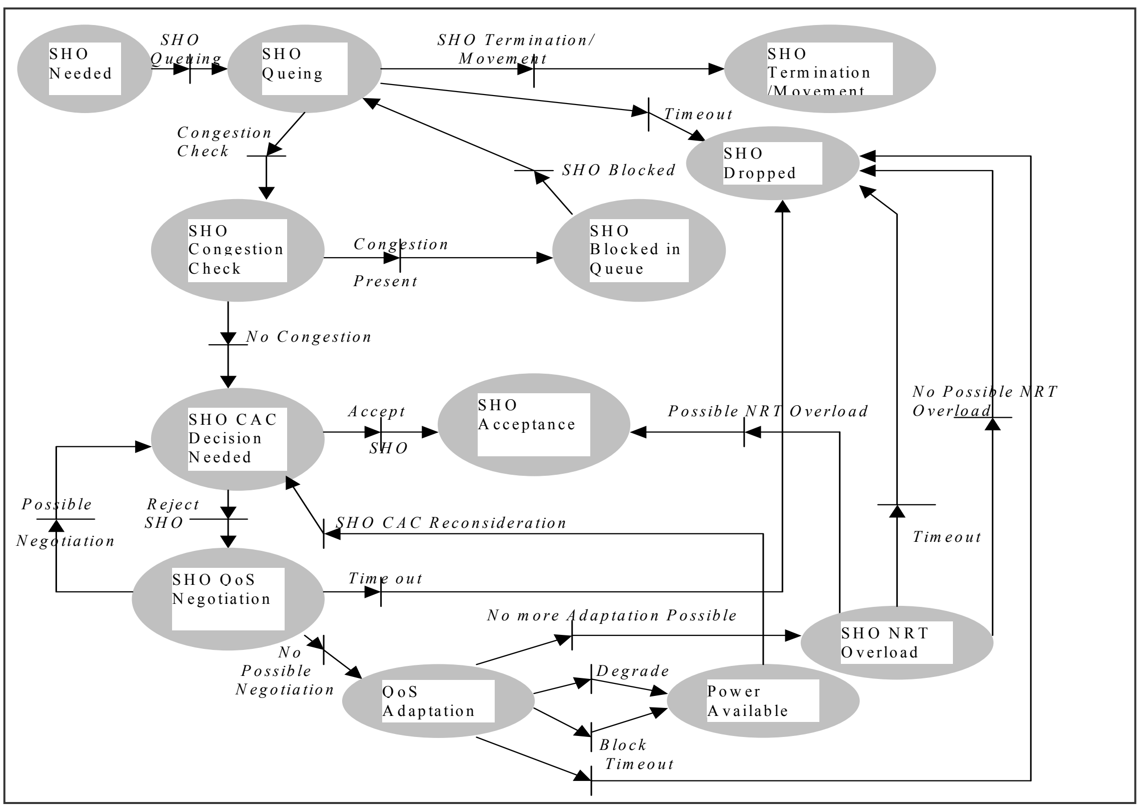

Fig. 3. SHO Process

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