A Survey of Call Admission Control Schemes in Wireless Cellular Networks

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Abstract- Call admission control (CAC) is a radio resource management technique aimed at providing fair quality of service (QoS) and grade of service (GoS) to mobile users in cellular networks. GoS refers the probability of blocking a new call request while QoS refers to the probability of loss of communication quality. This work presents an overview of the various techniques adopted for CAC bearing in mind core issues in cellular networks like coverage, capacity, throughput, diverse QoS requirements of mobile users, and blocking probability. We make effort, realizing these few issues, to comparatively analyze the performance of these schemes in order to highlight their suitability for a homogenous/heterogeneous traffic class, single/multi-cell environment in the uplink direction of a cellular CDMA network.

Index Terms- Radio Resource Management**,** Call Admission Control Schemes, Grade of Service, Quality of Service

1 INTRODUCTION

Presently, beyond 3G cellular communications systems are evolving to 4G technology based on orthogonal frequency-division multiple access (OFDMA) and multiple-input multiple-output (MIMO), with the goal of achieving data rates beyond 100Mbps. Optimal approaches to radio resources management (RRM) can significantly lower the cost of delivering data and multimedia services for the operators as well as improving the quality of services provided to users [1],[2]. The various techniques that are used in managing radio resources have been categorized in [1] into three sets. The first set includes frequency/time resource allocation schemes such as channel allocation, scheduling, transmission rate control, and bandwidth reservation schemes. The second set consists of power allocation and control schemes, which control the transmitter power of the mobile station (MS) and the base station (BS). The third set comprises call admission control, base station assignment, and handoff algorithms, which control the access port connection. Call Admission Control (CAC) is a technique used to grant or deny arriving calls access to the wireless network based on predefined criteria and possibly, taking the network load conditions into consideration. Traffic of admitted calls is then controlled by other RRM techniques such as scheduling, handoff, power and rate control schemes. Fig. 1 shows the possibility of an integration of different technologies for seamless connectivity in 4G network. Due to heterogeneity of 4G networks, wireless devices have to process signals sent from different systems, discover available services, and connect to appropriate service providers. Historically, mobile cellular communications have undertaken four evolution stages called generations, although there is a fifth stage under research development as shown on Table 1. A mobile cellular communication system shown in fig.2 can be divided into two segments: a radio access network that performs air-interface related functions and a core network that performs switching functions and interfaces to external networks, such as Internets or Public Switched Telephone Network (PSTN). The evolution of next generation technology (4G) is taking place at both the radio access network and the core network. The new air-interface standards include Wideband Code Division Multiple Access (WCDMA) and cdma2000-1X. The corresponding wireless networks are Universal Mobile Telecommunications Systems (UMTS) and cdma2000. A mobile access network's key function is to carry a baseband signal processing for effective communication over the air. It requires high throughput signal processing capabilities and new capacity enhancement techniques are continually needed.

The radio subsystem comprises the MS and the BS subsystem (BSS) consisting of one or more base transceiver stations (*BTS*), base station controller (*BSC*) for controlling several transceivers. The MS comprising the mobile equipment (ME) and the subscriber identification module (SIM) communicates across Um interface (air interface) with BTS. Each BTS defines a single cell and includes radio antenna, radio transceiver and a link to a BSC. The network and switching subsystem is responsible for call forwarding, handoff, switching and its components are the Mobile Services Switching Center (*MSC*), Interworking Functions (*IWF*), Integrated Services Digital Network (*ISDN*), Public Switched Telephone Network (*PSTN*), Packet Switched Public Data Network (*PSPDN*), Circuit Switched Public Data Network (*CSPDN*) as well as databases such as Home Location *R*egister (*HLR*), Visitor Location *R*egister *(VLR)*, and Equipment Identity Register *(EIR)*. This core network subsystem (NSS) provides link between cellular network and PSTNs, controls handoffs between cells in different BSSs, authenticates users and validates accounts, enables worldwide roaming of mobile users. The central element of NSS is the MSC. While HLR database stores information about each subscriber that belongs to it, the VLR database maintains information about subscribers currently physically in the region. The AuC database is used for authentication activities and holds encryption keys while the EIR database keeps track of the type of equipment that exists at the mobile station.

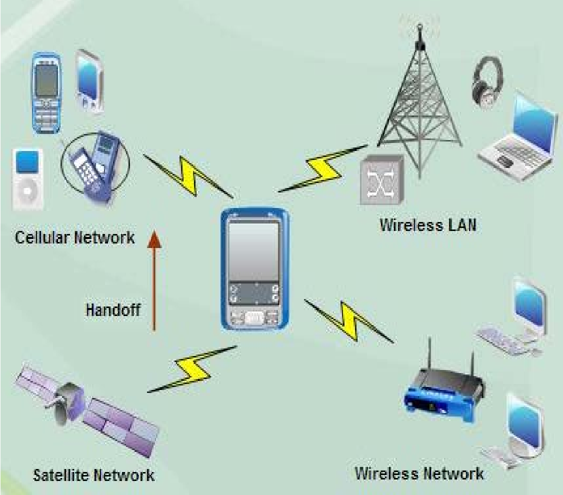

Fig. 1: Accessing Multiple Networks and Services in 4G Technology

Table 1

Evolution of Mobile Communications Systems

Property	**1G**	**2G**	**3G**	**4G**	**5G**
Starting Time	1985	1992	2002	2010-2012	Research concept, not under formal development
Representative Standard	AMPS	GSM	IMT-2000	UWB	
Radio Frequency (Hz)	400M-800M	800M-900M	1800M-2400M	2G-8G	
Bandwidth (bps)	2.4K-3K	9.6K-14.4K	384K-2M	20M-100M	
Multiple Access Technique	FDMA	TDMA, CDMA	WCDMA	OFDM	
Switching Basis	Circuit	Circuit	Circuit, Packet	Packet	
Cellular Coverage	Large area	Medium area	Small area	Mini area	
Service Type	Voice	Voice, limited data	Voice, data, limited multimedia	Multimedia	

While network operators are opt to accept more users for given amount of network resource in order to increase their revenue, the number of users that can be accommodated in the system is reversely proportional to the amount of resource used by each user. The simplest CAC is to limit the number of users admitted in the network. Traditional CAC strategies focused on increasing the radio resource utility by decreasing the service blocking probabilities. In Time Division Multiple Access (TDMA) or Frequency Division multiple Access (FDMA)-based networks, each user requires several time slots or frequency channels respectively. In a CDMA-based network, the interference-limited nature makes it difficult to achieve accurate admission control. Because of the co-channel interference, the amount of resources (power, bandwidth) required by each user is dependent on the number of users in the system, their geographical locations, and physical channel conditions. Thus, the admission control is to make a decision about whether a user should be admitted into the system according to the current traffic load and the QoS requirements of the user. The CAC problem was considered for voice only CDMA systems in [3] and for voice and data integrated systems in [4] while the authors in [5] proposed a framework of CAC for multimedia traffic in CDMA networks. Thus, the nature of the traffic (homogeneous or heterogeneous) and the cell environment considered (single-cell or multi-cell) could determine the scheme to use.

The rest of the paper is organized as follows: Section 2 presents a general idea of the call admission control concept and its role in RRM while section 3 comparatively analysis the performance of the various CAC schemes. Section 4 concludes highlighting the factors to consider before adopting a certain CAC scheme giving insights into the kind of admission control expected for seamless connectivity in emerging wireless technologies.

2 CALL ADMISSION CONTROL

RRM in wireless cellular networks is responsible for improving the utilization of the air interface resources. Generally, a mobile cellular network has a limited number of channels which could be frequencies, time slots or codes depending on the radio access technique used. These techniques are FDMA, TDMA, or CDMA respectively. Arriving calls are accepted or rejected in the network by the CAC scheme based on the predefined policy. The objectives of managing scarce radio resources include to guarantee the QoS for different applications, maintain the planned coverage, and optimize the system capacity. The coverage of WCDMA is assumed uplink limited in high-load scenarios. The capacity of CDMA networks depends on the reverse link (uplink) rather than the forward link (downlink). Uplink call admission control strategies therefore play a very important role in the performance of CDMA systems as it directly controls the number of users in a cell and thus limit the interference in the system. This work concentrates on the uplink direction.

In WCDMA networks, CAC handles all new incoming traffic, checks whether new connection can be admitted to the system and generates parameters for it [6]. This is done when a new connection is set up as well as during handoffs and bearer modification. If the air interface loading is allowed to increase excessively, the coverage area of the cell is reduced below the planned values (called “cell breathing”), and the QoS of the existing connections cannot be guaranteed. The reason for the “cell breathing” phenomenon is because of the interference-limited feature of WCDMA systems. Therefore, before admitting a new connection, admission control needs to check that admitting the new connection will not sacrifice the planned coverage area or the QoS of existing connections. Admission control accepts or rejects a request to establish a radio access bearer in the radio access network. The admission control functionality is located in the radio network controller where the load information of several cells can be obtained. The admission control algorithm estimates the load increase that the establishment of the bearer would cause in the radio access network. The requesting bearer can be admitted only if the admission control admits it; otherwise it is rejected because of the excessive interference that it adds to the network. Effectiveness and efficiency are two performance metrics to evaluate an admission control scheme. The effectiveness is to guarantee the QoS of the admitted traffic, and the efficiency is to maximize the amount of traffic admitted into the system. Nevertheless, when packet-oriented services are provided by wireless networks, network overloading can cause unacceptable excessive packet delay and/or delay jitter. The throughput level at the network or user level can also be dropped to unbearable levels. Therefore, CAC should be used to limit the network level to guarantee packet-level QoS parameters (packet delay, delay jitter, and throughput). In this case, the number of users, resource availability and/or an estimate of the packet-level QoS parameters can be utilized as an admission criterion [7]. The use of CAC to ensure a minimum transmission rate is more complicated in wireless networks because of user mobility (implying handoff and link quality variations), limited bandwidth, and mutual co-channel interference. From the network perspective, a new call admission has both rewards and penalties [1]. The reward comes from the utilization of network resources for a certain amount of revenue. However, at high network loading values, there is a potential penalty which can be manifested as deterioration in the QoS offered to the already admitted users and even potentially some call dropping. Hence, CAC can be used to increase the network revenue function based on the potential reward and penalty of admitting new calls. In this case, the admission criterion can be the number of users or an estimate of the probability of QoS deterioration (e.g. lower transmission rate than the acceptable level). There is a common belief among network operators and researchers as well that voice services should be given higher priority over data services. Also, giving higher priority to some classes inside the same service might be needed to differentiate between different user classes based on some criteria such as the subscription fees or the urgency of the call. Usually, duration of an emergency call is short in comparison to the duration of the personal or general calls. Many times an emergency call is blocked due to congestion and CAC can be used to reduce blocking of short duration emergency calls.

Several admission control schemes exist in the literature. Most admission control strategies are either wideband power-based admission control strategy and throughput-based admission control strategy. The former method computes the increase in the interference (power) caused by the establishment of a new user in the cell in uplink and accepts the call only if the total interference does not exceed a predefined threshold while the latter algorithm computes the increase in the load caused by the establishment of a new user in the cell in uplink and accepts the call only if the total load does not exceed a predefined threshold. Other schemes are comparatively discussed in subsequent sections.

3 COMPARATIVE ANALYSIS OF CAC SCHEMES

The call admission control strategies investigated in the literature are variedly classified into types. Generally, Deterministic Call Admission Control and Stochastic Call Admission Control are the two categories of call admission control schemes in cellular networks [8]. In deterministic CAC, QoS parameters are guaranteed with 100% confidence. These schemes typically require extensive knowledge of the system parameters such as user mobility which is not practical, or sacrifice the scarce radio resources to satisfy the deterministic QoS bounds. On the other hand, in stochastic CAC, QoS parameters are guaranteed with some probabilistic confidence. By relaxing QoS guarantees, these schemes can achieve a higher utilization than deterministic approaches. CAC schemes can also be classified as proactive (parameter-based) or reactive (measurement-based). In proactive schemes [9], the incoming call is admitted or rejected based on some predictive/analytical assessment of the QoS constraints. In reactive schemes [7], the incoming call might start transmission (by transmitting some probing packets or using reduced power) before the admission controller decides to admit or reject the call based on the QoS measurements during the transmission attempt at the beginning. In [10], CAC is classified based on the information needed in the CAC process. Some CAC schemes use the cell occupancy information [11]. This class of schemes requires a model or some assumption for the cell occupancy. Alternatively, CAC schemes might use mobility information (or estimation) in making the admission decision. The use of mobility information, however, is more complicated and requires more signaling. The information granularity used in CAC schemes can be considered at the cell level or at the user level. If a uniform traffic model is assumed, information of one cell is enough to represent the whole network condition. In a non-uniform traffic model, however, information from different cells is required to model the network status, which increases the information size. The third case, in which information of each individual user is considered, of course leads to a huge information size.

Furthermore, CAC schemes have been designed either for the uplink [12] or the downlink [13]. In the uplink, transmit power constraint is more serious than in the downlink since the MS is battery operated. On the other hand, CAC in the downlink needs information feedback from MSs to the BSs for efficient resource utilization. Applying CAC for both links jointly is crucial since some calls might be admissible in one of the links and non-admissible in the other, particularly for asymmetrical traffic. In the uplink direction of a wireless network, one CAC is based on the number of users and is referred to as number-based CAC [3] and the other is based on the interference level and is referred to as interference-based CAC [14]. The operation of the number-based CAC schemes is quite similar to the fixed-assignment FDMA/TDMA systems. That means that capacity is 'hard' as the number of users that can be admitted into the system is fixed. The Signal to Noise Interference Ratio-based algorithm computes the minimum required power for the new user and accepts it if it is not below a predefined minimum link quality level. In interference-based CAC scheme, the total interference at the base station is estimated at the time of new call arrival and the admission decision is made based on the result of comparison of this estimated interference with the predefined threshold. As shown in eq. (1), a new call in the uplink direction will not be admitted into the system if the estimated result of the total interference level is higher than the predefined threshold value. Thus, a call will be blocked if,

$$I_{own}+I_{other}+N_o + \Delta I > I_{th} \qquad (1)$$

where $I_{own}+I_{other}+N_o$ is the total interference of ongoing calls from own-cell, other-cell and thermal noise respectively, ΔI is the estimated increase in the interference caused by the new call and I_{th} is the threshold value for total received interference. Similar to the interference-based scheme is the power-based CAC scheme. Power control can be said to be perfect or imperfect. In perfect power control [15], received power at the base station, *BS* is fixed regardless of the user's location or shadowing fading channel condition. In imperfect power-based CAC when the load is high, power is regulated in order to help the system reach equilibrium [16]. The power levels are increased by the power control mechanism when interference increases to keep signal-to-interference-noise ratio (*SINR*) at the target value. Therefore, the level of power emitted with respect to the limit is adopted as load indicator in the admission decision. Using eq. (2), the signal power received by a MS can be computed taking note of shadowing effect loss and radio path loss [17] as follows:

$$P_{MS}(dB)=P_{BS}(dB) - A_s\ (dbB)-A_{PL}(dB) \qquad (2)$$

Where P_{MS} is the signal power received by the MS, P_{BS} is the signal power value emitted by the BS, A_s is the lognormal shadow loss, and A_{PL} is the radio path loss. From the knowledge of receiver sensitivity which sets the minimum received power P_{MSmin} to achieve a predefined quality level, the MS and the BS can communicate if the loss does not exceed some specified value, L_i.

Thus, we can show that:

$$A_s\ (dbB)-A_{PL}(dB) \leq L_i \qquad (3)$$

$$L_i = P_{BS}(dB) - P_{MSmin} \qquad (4)$$

However, A_{PL} (dB) is computed as:

$$A_{PL}(dB) = A_{OM}(dB) + P_{LC} \times 10\log(d) \qquad (5)$$

Where A_{OM} makes reference to one-meter losses, P_{LC} is the path loss coefficient, d is the distance between BS and MS.

In [18], CAC scheme is divided into two viz, local scheme and collaborative scheme. Local schemes use local information alone (e.g. local cell load) when taking the admission decision [19]. Collaborative schemes involve more than one cell in the admission process. The cells exchange information about the ongoing sessions and about their capabilities to support the sessions [20]. In the connection-based scheme by Ishikawa and Umeda [3], the load of a cell is the weighted sum of the number of active calls in that cell and the neighboring cell. The connections-based CAC derives the average cell capacity depending on the number of connections.

Certain CAC algorithms are to serve only single-class traffic such as real-time voice calls. To handle multiple classes of traffic, the authors in [21] proposed the partitioning CAC while in the authors in [22], proposed the threshold-based CAC. The partitioning scheme primarily partitions the total link bandwidth into three which corresponds to constant bit rate (CBR), variable bit rate (VBR) and handoff (HO) services or as needed. In the threshold-based scheme, the algorithm uses the effective load as an admission criterion and applies different thresholds for new calls, handoff calls, bandwidth requirement, power consumption, etc.

Another important solution to the decision making of call admission control is an optimization technique called multi criteria decision making (MCDM). The different types of admission control algorithms based on MCDM are classified into two, viz; utility-function based CAC and computation-intelligence based CAC. Utility-based adaptation algorithms are only used in the resource (especially bandwidth) allocation among on-going flows (calls or tasks). When a new call arrives, it is admitted only if it does not lead the mean utility in the future period to degrade below the pre-defined target utility. In the utility-function based CAC, the incoming calls are admitted using some utility or cost function based on multiple criteria or contradicting decision making parameters [23]. These algorithms are known to be optimal but in most cases are complex with high computational overheads [6]. The computation-intelligence based CAC uses evolutionary approaches like genetic algorithm, fuzzy logic, and artificial neural network or any of their combination [2], [18]. This approach helps to handle the uncertainty and imprecision problems in a multi-traffic environment by adding intelligence as well as learning capability to the call admission process thereby enhancing the system to make a good decision in accepting or rejecting a call thus keeping the blocking probability at minimum level. In [2], the authors considered user mobility information, cell load, loading factor and type of service request as multi criteria inputs into the fuzzy admission controller for a multi-traffic CDMA network and obtain optimal results with a blocking probability less than 0.01. Table 2 presents a comparative study of the various CAC schemes, highlighting their advantages and disadvantages as well as applicable traffic pattern and cell environment.

TABLE 2
COMPARATIVE ANALYSIS OF CAC SCHEMES IN WIRELESS NETWORKS

S/N	**CAC Scheme Adopted**	**Description**	**Advantage/Disadvantage**
1.	Deterministic	QoS parameters are guaranteed with 100% confidence	Difficult to obtain good knowledge of system parameters, radio resources are sacrificed to obtain QoS bounds
2.	Stochastic	QoS parameters are guaranteed with some probabilistic confidence	This can achieve higher utilization than deterministic approaches
3.	Proactive	Incoming call is admitted or rejected based on some predictive/analytical assessment of the QoS constraints	Parameter-based, needs prior information, more error prone, fast
4.	Reactive	Incoming call might start transmission before the admission controller decides to admit or reject the call based on the QoS measurements during the transmission attempt at the beginning	Measurement-based, no need for prior information, less error prone, slow
5.	Cell Occupancy Information	Requires a model or some assumption for the cell occupancy	No need for mobility estimation, needs cell occupancy model
6.	Mobility Information	Uses mobility information in making admission decision. If a uniform traffic model is assumed, it is similar to local scheme; If a non-	No need for cell occupancy model, more complicated and requires more signaling

		uniform traffic model is assumed, it is similar to collaborative scheme	
7.	Uplink	Transmit power constraint is taken seriously due to battery life of the MS	Near-far effect problem
8.	Downlink	Admission control needs information feedback from MSs to the BSs for efficient resource utilization.	No near far effect due to one-to-many policy
9.	Collaborative/ Connection-based	Involves more than one cell in taking admission decision	Capacity is not fixed; the load indicator of a cell is the weighted sum of the number of active calls in that cell and the neighboring cell
10.	Local/number-based	The admission is based on the number of users or resource utilization factor in own cell only	Implementation is simple; the number of users that can be admitted into the system is fixed.
11.	Partitioning	Admission control partitions the total link bandwidth into corresponding services e.g constant bit rate (CBR), variable bit rate (VBR) and handoff (HO) services	Outperforms conventional bandwidth allocation algorithms
12.	Effective bandwidth	The maximum number of admissible users is determined using the effective bandwidth concepts	Based on approximations though gives efficient results
13.	Throughput-based	computes the increase in the load caused by new user in the cell	accepts the call only if the total load does not exceed a predefined threshold
14.	Threshold-based	Uses effective load as admission criterion	assigns different thresholds for new calls, handoff calls
15.	Interference and SIR	The incoming call is admitted if the interference level (SIR) is less (greater) than a predefined threshold	Measurements needed
16.	Power-based	The incoming call is admitted if a feasible power allocation is determined	Power Control model needed
17.	Transmitted/received power	The transmit/receive power is used as the	Total transmit/receive power is an indicator of

		admission criterion	interference level
18.	MCDM	An admission policy is determined by optimizing some objective functions subject to signal quality constraints	Optimal CAC with signal quality constraint solved by Markovian Decision Process
19.	Utility-function	Incoming call is admitted only if it does not lead the mean utility in the future period to degrade below the pre-defined target utility	Needs some utility or cost function based on multiple criteria or contradicting decision making parameters, involves computational overheads, produces optimal results
20.	Computational-intelligence	Uses evolutionary approaches in artificial intelligence and their combinations to handle admission decision, e.g. fuzzy logic, artificial neural network, genetic algorithm, etc.	This can handle uncertainty and imprecision problems in a multi-traffic environment, adds intelligence and learning capability to the admission process

4 CONCLUSION

The task of ensuring the admission of more user calls in the midst of scarce radio resources is a challenging one in a wireless network. For better resource utilization, the admission strategy adopted should ensure that the quality of ongoing calls is not affected or degraded. Adopting a certain CAC scheme to solve this complex task requires taking into consideration the nature of traffic (homogeneous or heterogeneous) and the cell environment (single-cell or multi-cell). The number-based scheme is similar to the FDMA/TDMA technique and is not suitable for emerging 4G wireless network. Similarly, the local scheme which takes note of local cell information only, without considering the impact of other-cells on the session is equally not suitable for NGWN having diverse user applications and different access techniques co-existing seamlessly. With the growing interest in data and multimedia services, single-class CAC schemes are no longer sufficient and as a result, multiple-classes of service CAC schemes are more relevant, especially in 3G and beyond networks.

Ideally, in emerging cellular network, improving the QoS provided to users for more revenue generation by operators requires adopting a CAC scheme that takes into consideration the influence of traffic from own-cell and neighboring cells, especially in the uplink direction due to near-far effect. In conclusion, when multimedia, heterogeneous traffic are involved in a multi-cell environment, as is the case in beyond 3G mobile networks, the interference-based, power-based, threshold-based, collaborative, utility-function and computational-intelligence based schemes can be adopted for use. These schemes ensure optimal utilization of cellular network resources by handling multiple cell requests simultaneously thereby increasing total system capacity with reduced programming difficulties.

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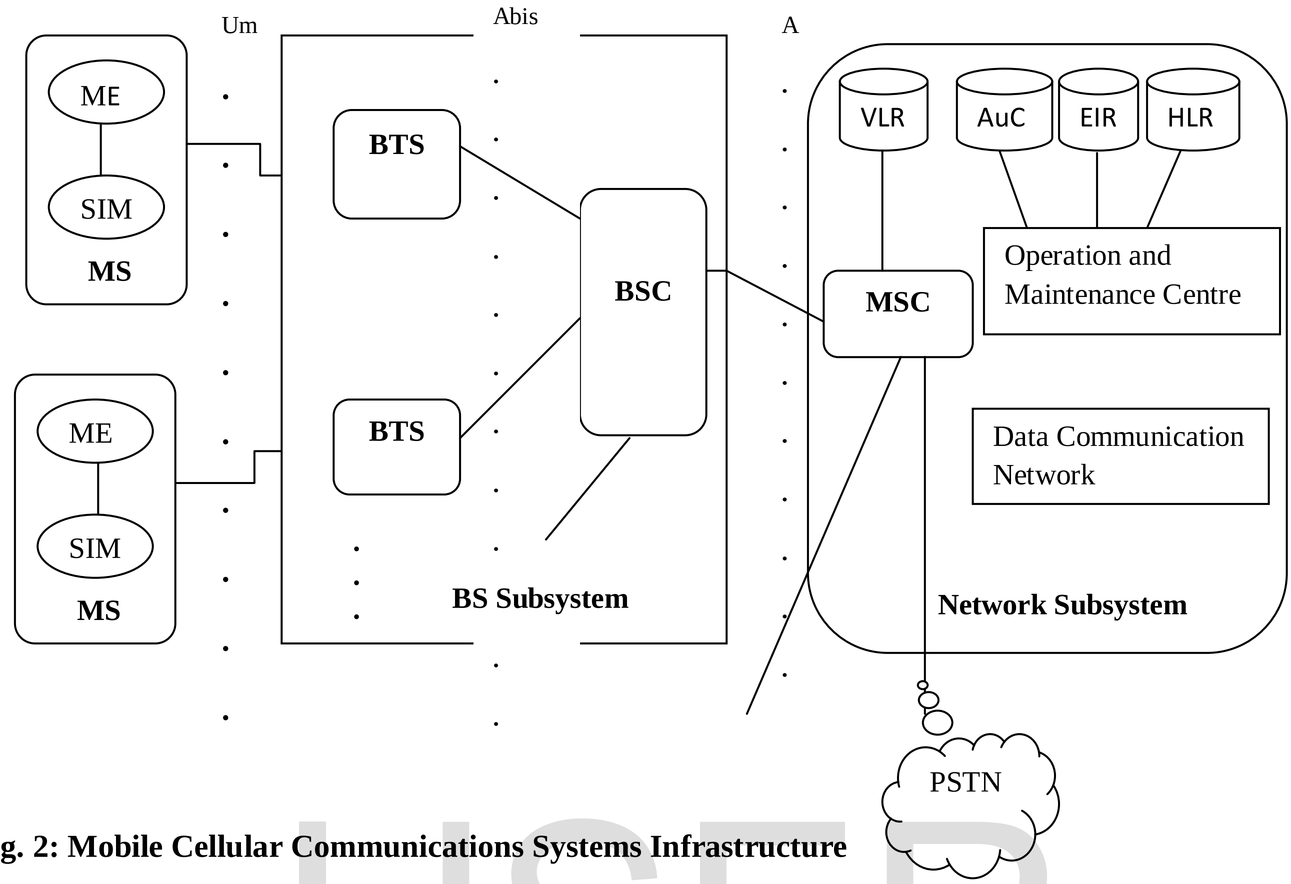

Fig. 2: Mobile Cellular Communications Systems Infrastructure