Using Public Cellular Networks to provide Wireless Access in a Campus Environment

Aveer Ramnath, Rex van Olst
School of Electrical and Information Engineering
University Of the Witwatersrand, Private Bag 3, Wits, 2050
Tel: +27 11 717-7216, 717-7220
Email: aveer.ramnath@wits.ac.za, rex.vanolst@wits.ac.za

***Abstract*—Students of today require computer and network access to be as widespread as possible. Universities have responded by deploying campus wide Wi-Fi networks, but in many cases the capital and operational costs prohibit this solution. This paper proposes a low cost alternative that utilises public cellular network infrastructure as a means of access to university resources, thus eliminating the need to deploy and operate a private access network. The proposed solution seeks to provide a free (or reduced) tariff to university users who access the university's public websites. The first component of the solution utilises an enhanced Gateway GPRS Support Node (eGGSN) to perform packet filtering in order to differentiate university traffic. The second component utilises an Intelligent Network Service Control Point (SCP) server to provide user authorisation (either explicitly using an authentication database or implicitly using geographical location) and differentiated charging. The Diameter Credit Control Application (DCCA) protocol is used to illustrate the messages between GGSN and SCP, thus demonstrating how the described service can be realised. Finally shortcomings are identified and future work is discussed.**

***Index Terms*—Wireless, campus, university, location, charging, billing, packet filtering, GGSN, Intelligent network, DCCA**

I. Introduction

Universities today are faced with the challenge of providing computer and network access for its student body. The demands for these services has increased substantially due to the nature of how information is delivered today. Twenty years ago, a student was not as reliant on computer and network access. The student would have consulted a physical noticeboard (timetables, course information or examination results), received a printed set of course material, and conducted research inside a library looking up print publications. In contrast the student of today would consult a virtual noticeboard on a website (in some cases having personalised information visible to them), download course material (slides, audio, video) from a course homepage, and make use of on-line repositories and search engines for access to digital resources.

Many institutions have recognised that dedicated computing facilities alone cannot cope with the numbers of students requiring access, and thus have embarked on plans to provide classroom and campus-wide wireless access [1] [2]. These networks are predominantly Wi-Fi and are installed and operated by the university, thus requiring a substantial capital expenditure as well as operational budget [3]. In many cases it is not feasible to provide ubiquitous access, thus requiring universities to target specific areas for deployment [4]. For many universities, especially those in developing countries, these costs are prohibitive.

A. Cost savings and increased user base

In this paper, it is proposed that the public cellular network, can be used to provide a similar service. This solution requires the university to enter an agreement with the mobile operator that allows users to utilise the public access network instead of a dedicated and private university access network. This would eliminate the university's capital and operational expenditure associated with its own private access network. In addition the end-user equipment is the mobile phone, instead of a Wi-Fi enabled device. Since many more users would have mobile phones, this solution would extend accessibility to a greater segment of the population.

B. Outline of paper

This solution relies on packet filtering, user classification and location to provide a free or differentiated tariff for the university user. Section II provides the background to the problem and related work. Section III provides a system overview, followed by Section IV which focuses on the the key requirements of the proposed solution. Section V then describes the network elements that are needed to implement the solution. Section VI and VII focuses on implementation by describing packet filtering on an enhanced Gateway GPRS Support Node (GGSN)and user classification on the Intelligent Network Service Control Point (SCP). Finally Section VIII discusses open issues, problem areas and options for further work.

II. Background and Related Work

The proposed solution takes elements from the various techniques described below, in order to synthesise a system that can provide a university user access to network resources via public network infrastructure.

A. Data billing landscape and challenges

Many in the telecommunications industry have recognised that billing on time used or data volume consumed is no longer sustainable for their business [5]. Even though it is acknowledged that growth in mobile data far outpaces voice services [6], data tariff plans on offer are very rudimentary, when compared to voice. Voice billing has differentiated tariffs dependent on destination (local, national, international, premium services), time of day (off-peak, on-peak), user context (location, network conditions), as well as other supplementary services (reverse billing, closed user groups, shared call). In contrast most data tariffs do not offer the above differentiated options. A sampling of four mobile operators across the globe (Orange UK , Vodafone India, Verizon USA, T-Mobile Germany) indicated that tariffs are based on data volume consumed. Furthermore industry leaders [7] have noted a move towards a flat rate for unlimited data.

Content billing, context billing, URL-based billing and Access Point Name (APN) based billing are noteworthy approaches proposed to improve billing opportunities. These techniques mostly rely on packet filtering to determine the URL of the server being accessed, as well as the type of content being retrieved. Packet filtering refers to the reading of the packet's header in order or perform some classification. It is currently widely used for traffic shaping by Internet Service Providers (ISP), in order to prioritise certain classes of traffic over others e.g. HTTP over P2P protocols.

B. Content billing

Content billing [8] provides a shared revenue stream with content providers (media, news, entertainment services). As an example, a user downloading a song from a content provider is not billed according to the file size, but a cost related to the content. The network operator can also act as an intermediary and perform billing operations on behalf of the consumer e.g. a mobile user pays for downloaded song by having the cost billed to the user's mobile account. This approach, as suggested by Kühne et al. [9], is favourable since the consumer does not need to worry about trust and security issues in dealing with the third party content provider.

C. Context billing

Context information such as the user's current location, time of day, profile, etc. can be factored into the billing use-case [10]. Two examples of location-based tariffs are: Favourite-Area (FA) billing, where a user receives a discounted tariff for calls originating or terminating in a chosen area, and Mobile-Local-Call, where a discount is applied if both parties are within a specific area [11]. Another noteworthy case is the network congestion based discount, where a users discount would be inversely proportional to network load in that cell [12]. Panagiotakis et al. [13] have considered the additional infrastructure needed to provide location-based charging in a UMTS network, however these additions are not warranted in the proposed solution, since only coarse location granularity is needed.

D. URL-based billing

URL-based billing [14] caters for different tariffs dependent on the URL accessed, and can be considered analogous to voice destination dependent tariffs. Despite products supporting URL-based tariffs being available for a number of years, only a few instances of such services could be found. A common implementation is for content portals such as Vodafone-Live! [15]. Users visiting this URL do not occur charges for browsing the site, but only pay for content which the user purchases.
Voice users are accustomed to cheaper tariffs for a national call compared to an international call. Similarly some operators are offering a reduced tariffs for browsing sites within a country's domain [16]. With voice services the operator's cost is lower for a national call compared to an international call. On the Internet this is not always the case, since a site's country domain is not an indication of the country where the site is hosted. Nevertheless, a tariff differentiated per country may be useful in attracting customers, and an operator will likely boost traffic on their local networks without increased costs on international bandwidth links.

E. APN-based billing

Access points can be used to separate traffic into different groups. A common scenario is for corporate customers to be assigned a separate APN [17]. All members of the corporation may use this dedicated APN for access to the corporate network or Internet. Frequently the corporate user will receive free access, with the corporation paying for reverse billing.

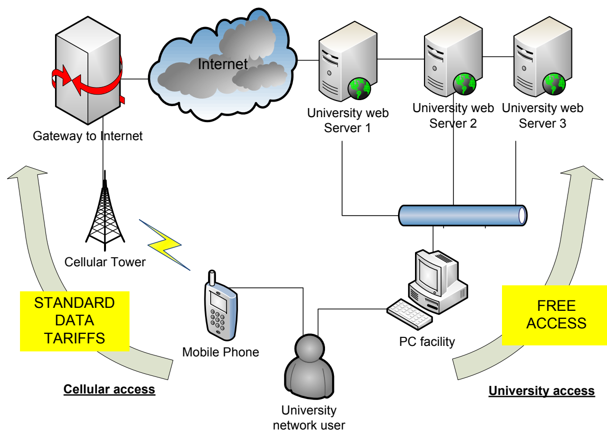

Fig. 1. Standard layout of cellular and Ethernet access on a campus

F. End-user access equipment

A further consideration in the developing world, is whether users will have access to the appropriate terminal equipment. Students would require a Wi-Fi enabled device (laptop or high-end mobile phone) to make use of campus Wi-Fi. In contrast, GPRS or 3G enabled devices are much more widespread and cheaply available, and thus offers a reduced barrier to entry for the average university student. Consequently this motivates the case for using public cellular networks as an access network. Its apparent that mobile devices have limited screen size and processing capability, thus making them unsuitable for viewing multimedia content. Whilst newer devices attempt to solve this problem, it will remain a problem on low end devices. For users who have a personal laptop, *tethering* would allow them to use the device as a cellular modem, and thus view content directly on the computer. In a similar fashion, users in residences may also tether personal or communal desktop machines which may not have network access. For the group of users without access to a computer, the traditional shared facilities remain the only option.

III. High-level description

When considering the implementation of the required service, it is useful to separate student network usage into two categories: (1) university resources (courseware, timetables, etc.) and (2) general resources as found on the Internet. University resources are considered as being more important and must be the minimum service provided to users. Consequently this paper focuses on providing option 1. It is assumed that all university resources are hosted on servers within the university domain e.g. `wits.ac.za`, these servers are reachable on the Internet, and the campus is covered by a data-capable cellular network.
A student can use a data-capable mobile phone to access the university resources in the same way as general resources are accessed, since all university resources are publicly accessible. In many cases the prohibiting factor is the cost charged by the mobile operator. Figure 1 depicts the cellular and Ethernet access networks that are available to a student, and the associated charges.

IV. System requirements

It is proposed that the cellular operator enter into an agreement with the university such that users receive a discounted rate (possibly

TABLE I
ADVANTAGES AND DISADVANTAGES IN USER CLASSIFICATION TECHNIQUES

Technique	Advantage	Disadvantage
Authorisation database	Not confined to geographic location. Better accounting of users.	Requires effort to add, remove and administer users.
Location filtering	No effort for user administration All visitors to university have immediate access.	Only available within chosen locations.

charge-free), provided the traffic is served from within the university. The university subsidises the service, and is billed by the mobile operator. This service is analogous to the toll-free voice service provided by network operators, in which calls to certain destinations are free to the user and are reverse billed to the called party.

There are two primary components to this system: (1) differentiating university traffic from other traffic on the network - *traffic classification* (2) determining if the user of the service is a member of the university community - *user classification*. These components are discussed below, focusing on how this service can be realised in GPRS compliant networks i.e. 2.5G-GSM/GPRS and 3G-UMTS architectures. GSM networks are by the far the most widely deployed technology [18], with an especially strong footprint in developing countries, and GPRS is an extension to these networks to support data traffic. The ubiquity of these networks further motivates the case of greater terminal mobility as discussed earlier in Section II-F.

A. Differentiating university bound traffic

The ability to separate university traffic from other traffic for the purposes of charging can be implemented using packet filtering. For this application the URL field in the HTTP packet header [19] is used to distinguish university bound traffic. It is beneficial that the required field is within the packet header, as this task is easier to accomplish compared to extracting information from the message body (packet inspection).

B. User classification

Having achieved differentiated charging capability, a mechanism for checking if a user is allowed the service is needed, hereafter referred to as user classification. The outcome of this operation is to classify a user as being authorised or not. An authorised user will receive subsidised access to the service, whilst an unauthorised user will be charged the standard data tariffs applicable.

Two basic techniques are suggested for classification: (1) authorized user database, and (2) location filtering. In the former case, a database of authorised users is interrogated to check if the current user is present. A matched entry in the database classifies the user as authorised. In the latter case, the user's location is used to grant authorisation. All users located within the campus (or other permitted off-campus locations), would automatically be granted access. Some of the advantages and disadvantages of these techniques are listed in Table I. User classification needs to be performed during the initiation of a session. This task cannot be implemented on the GGSN and requires interaction with an application server.

V. NETWORK ELEMENTS

Before considering the implementation of the above requirements, it is necessary to describe The General Packet Radio Service (GPRS) and Intelligent Network (IN) architectures.

A. GPRS architecture

The General Packet Radio Service (GPRS) standards add the ability to transport packet data in a GSM or UMTS cellular network. The two principal components in a GPRS network, are the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) [20]. The SGSN is responsible for receiving and forwarding packets between the mobile device in its serving area and the core network. The GGSN provides interworking between the GPRS network and external packet networks such as the Internet. The GGSN also interfaces to billing and online-charging systems, and this aspect is relevant to the proposed solution. Many vendors [14] [8] have extended the functionality of the GGSN by adding packet filtering and inspection capabilities, and this provides the ability to separate, meter and charge traffic dependent on its destination. This is commonly referred to as the enhanced GGSN (eGGSN).

B. Intelligent Networks

User classification must be performed at session initiation, and requires interaction with an application server. In GSM/UMTS networks, the Intelligent Network (IN) application server is suited to this task. IN servers were introduced in telecommunication networks to speed up service development and deployment [20]. The key concept is that the service logic is externally hosted on a separate platform - the IN server (Service Control Point in IN terminology). This separation permitted services to developed and rolled out in a much faster manner compared to updating core network elements.

The IN architecture has proven its longevity, and has evolved from its origin in fixed networks [21], through current mobile networks [22], and its inclusion in next generation architectures [23]. During its evolution, a number of protocols have been developed to cater for the specific applications. These are summarised in Table II.

The IN architecture permitted services such as number translation, toll-free calls and online charging to be developed [20]. Online charging (prepaid) has unquestionably become the most popular IN service, whereby users are charged in real-time from their prepaid account. Prepaid has lead to substantial growth for network operators [24] and is the predominant mode of access in the developing world. In this service the user's profile, which includes the users account, is stored on the IN server. When a call is initiated the user's account balance is checked and updated as the call proceeds.

Figure 2 is a simplified message sequence chart of the online charging application used in a prepaid data (GPRS) session. The GGSN initiates a session by contacting the IN server. Following successful user lookup and session authorisation, the GGSN requests data quota e.g. 500 kB from the IN server for a charging category. An example of charging categories that correspond to URL filters are given in Table III. The IN server would calculate the cost of the quota and check if the user has sufficient funds. If funds are available, the IN would grant the quota to the GGSN. Once the user has consumed the quota, further quota would be requested.

It should be noted that the online charging can be implemented using other protocols as given in Table II. The Diameter Credit Charging Application (DCCA) protocol [24] [25] is presented in this example, since this is the basis for the implementation of user classification. The applicable DCCA messages are shown in Figure 2. The principal messages applicable in DCCA are the Credit-Control-Request (CCR)

TABLE II
ACCESS TYPES AND PROTOCOLS FOR IN SERVICES [22] [24]

Type of Network	Type of access	Applicable protocol
Fixed-line	Voice	Intelligent Network Application Protocol (INAP)
Mobile	Voice Short Message Service (SMS)	CAMEL Application Protocol (CAP)
	GPRS Data Unstructured-Supplementary-Service-Data (USSD)	Diameter Credit Control Application (DCCA)

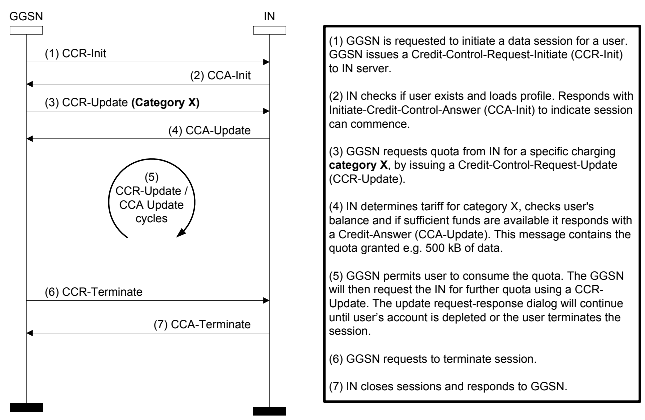

Fig. 2. Prepaid GPRS charging implemented using Diameter Credit Control Application (DCCA) protocol

from GGSN to IN, and Credit-Control-Answer from IN to GGSN. The CCR-Initial is used to initiate the session, CCR-Update is used to request quota from the IN and report quota consumed, and CCR-Terminate is used to close the session. These messages will be referenced in the implementation described later.

VI. IMPLEMENTING PACKET FILTERING

A. eGGSN metering and differentiated charging

The following example illustrates how the eGGSN can charge different tariffs dependent on the traffic destination. When a mobile user establishes a packet data session, the eGGSN will screen the URL field of HTTP packets passing through the gateway from client to server. The eGGSN has been configured for 3 charging categories: (1) `*.wits.ac.za` - traffic bound for Wits University, (2) `*.za` - all traffic to servers in ZA domain (South Africa), (3) all other traffic. Each category has a different tariff associated with it, as shown in Table III. Consider a user starting a data session and browsing to `www.google.com`. This does not match category 1 or 2 and will start a meter of category 3. Later the user visits `www.ee.wits.ac.za`. This matches category 1 and a separate meter is then started. The amount of data consumed within each meter is then used for billing the user. This example is depicted in Figure 3. Billing can be done in real-time (as is done for prepaid users) or in post-processing (as is done for contract postpaid users). Records from the eGGSN or billing system can also be used to determine the

TABLE III
EGGSN CATEGORIES PROVIDING DIFFERENTIATED CHARGING

Category	Description	Mask	Cost
1	University traffic	`*.wits.ac.za`	0
2	South Africa traffic	`*.za`	1
3	All other traffic		5

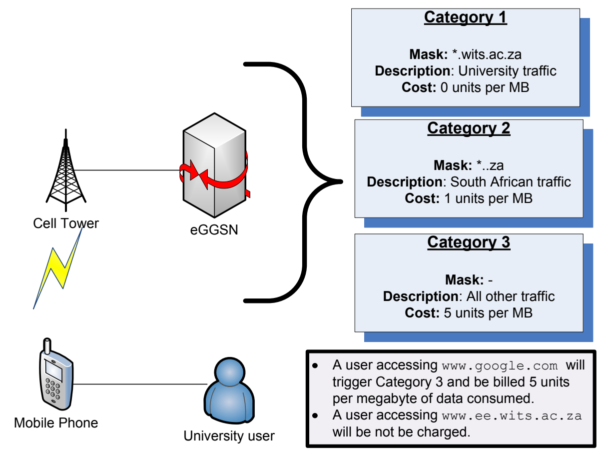

Fig. 3. eGGSN metering allows different tariffs dependent on URL

amount of data consumed in this use case, thus permitting reverse billing of the university.

VII. IMPLEMENTING USER CLASSIFICATION

A. Implementing authorisation database on IN server

User authorisation requires that the user's profile contains information of whether the user has access to the service. As discussed in section V-B, the IN server stores fields such as account balance, expiration date, etc. in the user's profile. It is proposed that the user profile is extended to include a list of subsidised charging categories. An example profile for a university user would be `Subsidised-Charging-Categories:=(1,2)`, where the categories are defined in Table III. If a university user attempted to access a university website, this list would be searched for Category 1. Since this entry is present in the users profile, the user will be granted quota and would receive the subsidised tariff. Similarly a non-university user would receive a standard tariff since the user's profile does not contain Category 1. As shown in Figure 2, the above mentioned logic would be performed on the IN server when message 3 (CCR-Update) is received.

B. Implementing location filtering on IN server

Location filtering requires the use of the user's location in determining if access should be granted. If a user is located within the campus environment, the user should receive a subsidised tariff. By examining the the CCR-Update message, as defined in [26] [27], it is apparent that the users location is available in the field `3GPP-User-Location-Info`. The value in this field represents a geographical location identifier for the the cell or serving area [26]. Upon receipt of this CCR, this field can be extracted and used by the IN server to determine if the current category should receive a subsidised tariff, as indicated by the user's location. The IN service would contain a list of locations for which a subsidised category is

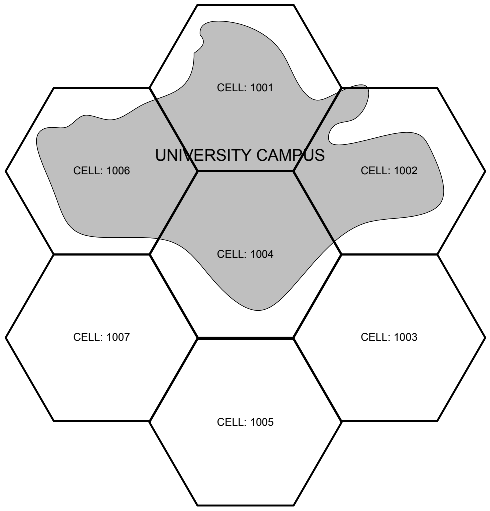

Fig. 4. Cells which cover campus

TABLE IV
MAPPING SUBSIDISED CATEGORIES TO ALLOWED LOCATIONS

Category	**Description**	**Allowed Location**
1	University traffic	Cells=[1001,1002,1004,1006]
2	South Africa traffic	Cells=[*] - No restriction
3	All other traffic	Cells=[*] - No restriction

permitted. Figure 4 depicts the cells covering the campus, and Table IV shows the corresponding location table administration on the IN server. During session initiation for a chosen charging category, the IN server must check if the user's current location should receive a subsidy.

VIII. SHORTCOMINGS AND FUTURE WORK

It has been noticed that a shortcoming of the proposed solution is the separation of destination domains. In the case of a voice telephone call, there is only a single destination - the called party. Thus, for the purposes of billing there is no ambiguity. However in the case of a destination web-page, a number of the objects on the page may be be resident on servers outside the domain. As an example, a lecturer's course home-page may include an embedded video tutorial from a video hosting site such as YouTube. When the user loads this page, the video preview image would be loaded from the video hosting site and consequently trigger a separate charging meter on the GGSN. The user would then be billed a separate tariff even though the user expected a subsidised tariff for the university domain. Approaches to resolving this issue are summarised in Table V, and require further investigation. It is likely that an APN-based billing solution that incorporates location filtering can provide more general network access to university users, but requires user administration of a specific APN.
Future work will focus on a trial project with a network operator and university to test the viability of the general solution presented, and evaluate the strengths and weaknesses of the options put forth.

IX. CONCLUSION

In order to meet the growing needs of today's university student for network and computer access, this paper proposes the use of public network infrastructure. The proposed solution is motivated as an alternative to Wi-Fi networks, on the basis of reduced capital and operational costs. As such the implementation focuses on making use of existing network infrastructure in 3GPP networks, and taking advantage of the large user base with the appropriate terminal equipment.
The focus of the solution is providing a university user access to university resources at a reduced or free tariff. University traffic is detected by making use of packet filtering on the GGSN. This differentiated traffic category can be charged a different tariff by employing the capabilities of the Diameter Credit Charging Application (DCCA).
A second requirement is restricting this type of access to authorised university users. The first method relies on the use of an authorised user database. This can be achieved by extending the user's profile on the Intelligent Network server. The second method grants access to users who are geographically located on the university campus. By making use of appropriate location fields in the DCCA application messages, it is possible to provide location based authorization. Finally shortcomings in the solution are identified and motivations for future work are given.

TABLE V
RESOLVING THE PROBLEM OF SEPARATING DESTINATION DOMAINS

Approach	**Description**	**Issues**
Separate portal	Access restricted to a portal site which exclusively hosts university content.	Extra administration for content creators to upload data to portal. Limits open capability of web to link to other resources.
Dedicated access point (APN) with traffic blocking	Use a specific APN to access subsidized content. The APN would block requests from outside domain	Service requires configuration by users. Limits open capability of web to link to other resources.
Dedicated access point (APN) with fair usage policy	This APN would not restrict traffic to university domain, but allow general Internet access. To prevent abuse of access, GGSN would implement a fair-usage policy (limit file size, block streaming media, etc.)	Service requires configuration by users. Provides more comprehensive service to users.

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Aveer Ramnath is a Lecturer in the School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, South Africa. Prior to this he worked as a Software Team Lead at Nokia-Siemens Networks, specialising in online charging systems.

Rex van Olst is Associate Professor in the School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, South Africa.