An Autonomous Cognitive Personal Mobile Phone for Radio Access Cost Optimization

Adrian Muscat, Saviour Zammit, and Therese Attard
Department of Communications and Computer Engineering
Faculty of ICT, University of Malta
Tal-Qroqq, Malta
Email: adrian.muscat@um.edu.mt, saviour.zammit@um.edu.mt, attardtherese03@gmail.com

Abstract— **This paper proposes an autonomous cognitive mobile radio that optimizes the use of radio resources from the user point of view. The network functions that are required to provide a service with the least amount of user intervention are discussed. A computationally inexpensive heuristic algorithm that manages the call setup is developed. The algorithm makes use of past experience to determine the optimal voice call connection that either minimizes the cost for the user or minimizes the call setup time. The transient properties of the algorithm are analyzed via simulation and the implementation of the cognitive radio on a commercially available smart phone is discussed. Technical hurdles and issues in implementing a handover function and a mechanism that allows a subscriber to share a private line and ensure fair billing are discussed.**

I. Introduction

Digital mobile cellular telephone systems are inherently limited by two issues; (a) the data rate falls with increased mobility, and (b) unnecessarily over-engineered and expensive for areas characterized by high density and low-mobility. Digital cordless, characterized by low-cost and low-power, telephone systems were developed to address these problems. The idea is to service static and slow moving phones in the higher density areas with low-cost low-power micro and pico-cell systems and fast moving phones with more expensive macro cell cellular networks. The best effort in cordless telephone networks development is perhaps the DECT (Digital European Cordless Telephone) system that in one particular configuration piggybacks on already existing underutilized wired telephone systems. This development was carried out in parallel with the development of the 2G cellular system, GSM (Global System Mobile) and the idea was to use DECT when at home, at the office or in buildings and GSM for the greater outdoor coverage. Such a system is shown in fig.1. In the late 1990's dual service phones that can be used over the combined DECT-GSM networks were made available, but unfortunately had a very short lifetime. Essentially, cellular operators did not like the idea of offloading traffic to the fixed network operators. The business model was therefore not the right one [1]. DECT was therefore limited in the implementation of private networks. The concept of mixing low-power with high-power systems is the optimal solution and was reconsidered again for 3G networks. In Europe two systems, Universal-Terrestrial Radio Access Networks (UTRAN-FDD) and UTRAN-TDD were projected to work together. Nevertheless for the second time cellular operators chose not to take up the option.

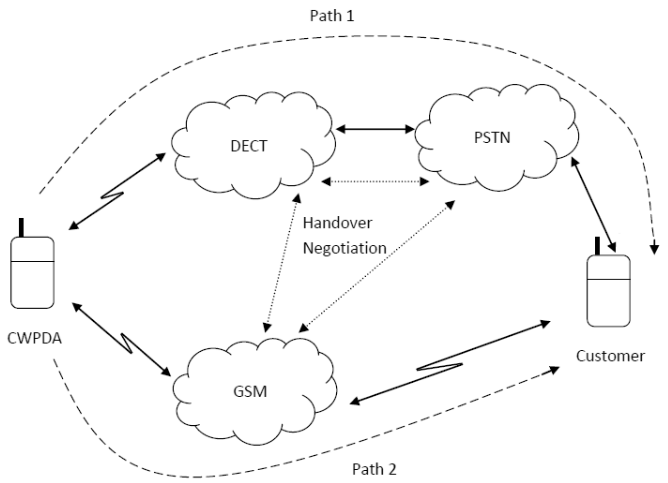

Fig. 1. A combined DECT-GSM wireless access system.

The popularity and widespread deployment of WiFi networks prompted mobile phone manufacturers to add WiFi modules with added support for VoIP telephony. The concept of low-power/high-power dual service radio operation was therefore re-considered. Smart phone sales were expected to make up more than 50% of all handset sales in 2010, [2] and smartphone users are opting for VoIP over WiFi rather than cellular systems whenever they can, [3]. Naturally, this trend depends on the widespread deployment of Wifi systems and more importantly the cost model adopted. Systems that combine GSM or 3G networks with VoIP over WiFi are therefore being proposed and studied. Research shows that operators can register significant gains in revenue or competitive advantage if they take up this concept. For example a cellular network operator can offer customers cheaper calling rates by offloading some of the calls to a lower cost WiFi network, [2]. So far, some cellular mobile phone operators are offering seamless switching between the lower cost WiFi home network and the cellular service for a monthly charge, [4]. This lowers congestion on cellular network and slows down the pace of network upgrades. Hence infrastructural costs are reduced. It therefore benefits the operator, but not so much the customer unless the operator offers cheaper cellular calls. Operators can extend this service to public buildings and encourage users to offload voice calls to the Wi-Fi network by offering them cheap or free call rates in return [5]. In this case, WiFi networks will handle static calls from mobile phones and the cellular infrastructure can therefore be downsized. If the WiFi zones are selected carefully this should result in an overall lower cost infrastructure and the operators can reduce the rates of calls carried over the heterogenous network, while still making sufficient profit gains, leading the operator to be more competitive [4].

This paper considers a different approach to cost minimization and discusses ways of how the network functions are implemented from the user's end while minimizing manual intervention. An Autonomous cognitive mobile radio (ACMR) terminal is proposed to carry out the necessary functions. The learning algorithms are developed by simulating the user's behaviour when trying to minimize the cost of a voice call. To this end, most people consider factors such as recipient's location at the particular time instant and try to predict which carrier would offer the cheapest call. Users also negotiate handovers upon receiving feedback when engaged in a voice call.

The rest of the paper is organised as follows; the next section discusses the ACMR architecture and how the necessary functions can be implemented on the user's side. Section III describes a call setup algorithm and its transient performance and section IV discusses the implementation of the ACMR on a smart mobile phone. The last section concludes the paper.

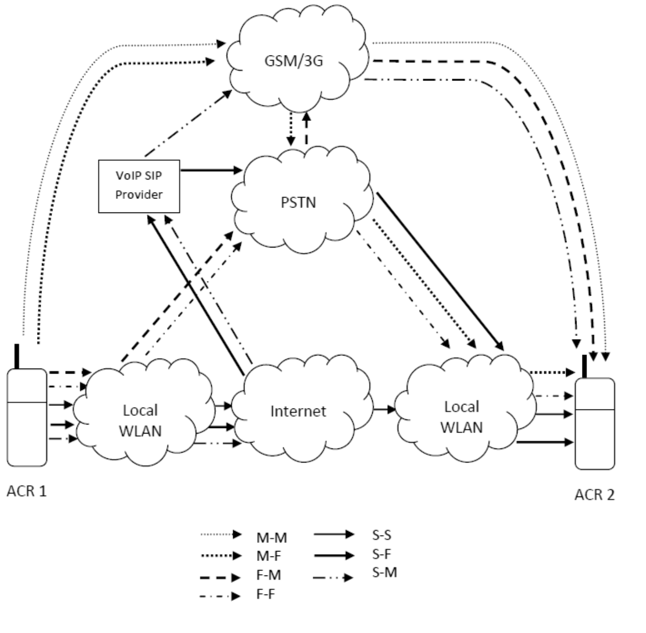

Fig. 2. The ACMR in a system that comprises cellular networks (M), PSTN switched systems, internet systems (S) and low-power radio systems that piggyback on fixed PSTN lines(F).

II. The ACMR Architecture

Fig.2 depicts how an ACMR interfaces to a system of interconnected networks. The networks shown are cellular mobile networks (GSM/3G), switched wired networks (PSTN/POTS) and the internet comprised of the global back-bone as well as WANS and LANs. ACMR can support radio connections to the high power cellular systems as well as to low-power systems such as DECT or WiFi. The low-power radio gives access to the PSTN and internet. Two ACMRs are shown in fig.2 and the available connections or paths from ACR1 to ACR2 are highlighted. The aim of the cognitive algorithms embedded in the ACMRs is to connect the user to another user in possession of an ACMR or to a standard non-ACMR terminal optimizing or guaranteeing a user specified preference, for example lowest cost. The ACMR can either work on its own, in a peer-peer session and may even be supported by ACMR base stations that host databases. The latter is albeit closer to the unified radio concept, [6].

Fig.3 depicts the ideal ACMR architecture and how it interfaces to networks and other ACMRs. In standby mode the ACMR scans the radio networks to determine the networks available to which it registers. The ACMR may use knowledge on geographical position of the calling ACMR as well as that of the receiving ACMR in the decision making process. When on its own the ACMR uses self knowledge. In a peer-to-peer session the ACMRs can negotiate with each other and can carry out handover functions. ACMRs can also share call setup information and in the presence of ACMR base stations can download information aggregated in base station databases. For example an ACMR can register its current connectivity map on a public secure database. The ACMR is expected to work with incomplete information. Info comes from database within the ACMR itself and other fixed databases. Distributed collection can also be considered where different ACMRs pass information from one to the other. Privacy and Security issues may have to be considered in these cases.

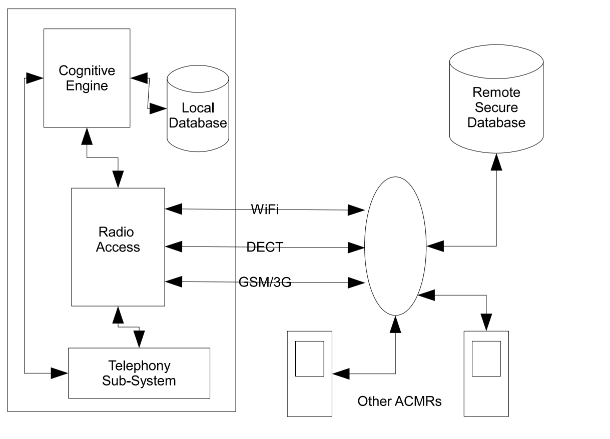

Fig. 3. The proposed ACMR architecture and its connection to networked components and other ACMRs.

The functions that are being considered are (1) the minimization of the cost for a voice call or the minimization of call setup time, (2) a seamless handover from one network to another during a call, and (3) billing the user when *borrowing* a third party fixed line. In these discussions any contractual obligations that preclude a function to be carried out are ignored and only technical characteristics are considered. The minimization of cost is dealt with in section III. The rest of this section discusses the implementation of the other two functions.

In the absence of network information resident on a central server, two communicating ACMRs have to negotiate a handover autonomously. Suppose that a fixed-WiFi($ACMR_1$) to a cellular($ACMR_2$) call has been setup between two ACMRs. During the call $ACMR_2$, moves into a fixed-DECT zone. The call can then be handed over to the fixed-DECT network, assuming that it is cheaper. This information has to be transmitted between $ACMR_1$ and $ACMR_2$ for example, by modulating digital data over the audio channel. This method will add some audible but acceptable *noise* in the channel of very short duration. Needless to say, prior to taking a decision on a handover, the ACMRs will estimate whether a handover results in a cheaper call or not.

In theory mobile users can *borrow* unused bandwidth on wired lines, such that quasi-static voice traffic can be off-loaded to these networks. The third function is related to a user *borrowing* such a third-party fixed line. This is the most difficult function to implement as it is necessary to have a mechanism of how to bill the user borrowing the line and the line subscribers have to be encourage to offer their line to third parties. Such a system will convert a private line to a line shared by the public. A few POTS (Plain Old Telephone System) operators offer a service whereby access is granted via a code and the subscribers receive separate bills. This system enables the function under discussion to operate as intended. In the case of a POTS connection one call can be serviced at a time. In the case of a VoIP connection over WiFi more than one call can be supported.

III. The Call Setup Algorithm

The ACMR must interact with the environment in order to be context aware. This can be achieved through the cognition cycle, proposed in [1], that consists of five phases; (1) Observation: The environment is observed so that data such as current location and networks available are collected, (2) Orientation: The impact of the collected environment data on the ACMR system is analyzed, (3) Decision: The search of a solution for a possible configuration that has the user's needs at its interest, (4) Action: The ACMR is re/configured to meet the user's objectives, like, for example, changing the network, and (5) Learning: The decisions are evaluated so that future orientation phases are more effective than the previous one.

In the context of ACMRs, the opportunities for learning vary from the user's interaction with the terminal to the ACMR observing its user's actions. For example, the mobile device observes the user sending emails via wireless networks, [7]. The user sends emails when on the train whilst traveling from home to work, and also while at work. The company's WLAN is used when the user is at the company premises. Hence, the Cognitive Radio could ask the user whether s/he would like the Cognitive Radio to autonomously use the company's WLAN when available instead of the more expensive cellular data services.

The choice of a machine learning technique is an important consideration in the design of a cognitive radio. Rote, decision trees and reinforcement learning are are discussed in [8]. Rote learning, memorizes the result of a set of conditions such that when in the future, the same conditions are encountered, the memorized result is used. This learning technique is suitable if the number of situations is limited. A decision tree can be defined as a sequence of choices, where the sequence's path depends on which choices are made at every decision node. This approach is a solution space search problem, which means that for a given state, alternative actions are given. Reinforcement-Based Learning calculates the success of an action, where success is defined by how much the actual result is close to the desired result. The weight is then assigned depending on the extent of the success. Hence, the action is reinforced in future events.

In this paper a version of the rote learning or memorization technique based on a table look-up is proposed and its transient performance is studied. The table itself does not store absolute positions but stores probabilities of connectivity and call duration. These two variables are updated at every event, an event being a call setup request by the user. A call in the reverse direction is not included but can be included. Table I depicts an example for the probability of connectivity. Such a table is built up for every contact included in the directory of the ACMR. All the numbers on which a contact can be reached are included in this table. Table I shows two possible numbers, a PSTN number and a GSM number. One single day is split up into a number of time slots, enumerated in the first column. The greater the number of time slots is the better the resolution but the larger the memory requirement. For each time slot the number of attempted calls and the number of answered calls are recorded. From this the probability of the receiver being connected to a particular network in a given time slot is calculated. Initially, all the parameters in the table are set to zero and are then updated after event. A Similar table stores the average duration of calls carried out during a particular time-slot and to the respective contact number. This table is also updated at the end of each call event.

The probability of connectivity and the average call duration are used to decide on the connection setup for a call setup in the future. From these two tables the probability of answering a call and the call duration is estimated. The call cost is estimated and a temporary decision table is derived, table. II. From this table the ACMR chooses a network and based on whether the user opts for the absolute cheapest call or for a speedy setup takes a decision and attempts to setup a call. The tables are updated accordingly. This learning method simulates the way human beings go about to take a decision based on past experience and what they can remember.

A simulation is carried out to study the transient performance of the algorithm. Various subscriber profiles with typical call patterns are modeled as in [9]. Results confirm that the ACMR optimizes the cost or favours lower cost options

TABLE I
PROBABILITY OF CONNECTIVITY

Contact Name : Gorg Borg				
	Number 1 (e.g PSTN)		Number 2 (e.g. Cellular	
Time Slot	#Calls Answered	#Calls Attempted	#Calls Answered	#Calls Attempted
1	0	3	1	2
2	1	2	0	2
3	2	2	1	3
-	-	-	-	-

TABLE II
DECISION TABLE

Network	Duration in minutes	Prob of Availability	Cost
S-M	11	93%	0.80
S-S	11	45%	0.04
M - M	11	93%	1.60
F - F	11	15%	0.15

for recipients that are characterized by a stable lifestyle. In this case the probabilities converge with a 95% degree of confidence to steady state after approximately 15 events for a given time slot. The transient performance for the whole table or for the time slots that are of major interest however depends on the time slot size. The smaller the time slot is the longer the convergence time. The study reveals that it could take up to 3 months for the table to converge in the case of popular contacts and when the time slot is set to 1 hour. This is an area for further research and it is further discussed in section V.

IV. The ACMR on a smart phone

The partial implementation of the ACMR on a commercially available smart phone brought up a number of issues. The algorithm described in section III was implemented on a NOKIA E71 SmartPhone, that supports GSM and 3G high power radio, WiFi with a built in SIP client, GPS-A module and 8GB of memory. This phone can therefore support the following network connections; (1) a switched cellular call, (2) a VoIP SIP call over the internet, and (3) a switched PSTN call when coupled with a VoIP-PSTN gateway. A table of time-dependent tariffs was prepared and written to the phone's memory. The table compilation can be a daunting task especially for cellular tariffs. Call duration and activity for cellular setups are normally available directly, where as call statistics for VoIP calls need to be calculated. Call setup times are long for SIP initiated calls and therefore needs to be taken in consideration when the user needs a very short setup time. Practical and affordable VoIP gateways for the home user are not yet easily available. However corporate VoIP systems are now quite common. Furthermore free public WiFi access is very limited and therefore the cost of WiFi network subscriptions needs to be taken into account. Furthermore a WiFi connection drains a relatively high amount of energy from the battery to the point that the viability of a WiFi device for the ACMR is compromised. A much more power efficient low-power system such as DECT or HiperLAN5 should be instead considered.

V. Conclusions and Further Work

The studies carried out on the ACMR algorithm have shown that with an adequate number of calls per day, the algorithm converges to the call pattern of the contact within three months, although for the mostly used numbers the time could be much less. The simulation also point out that convergence to theoretical values occurs mainly on weekdays rather than on weekends. This demonstrates that good results are obtained when the contacts lifestyle is rather periodic. Hence, the algorithm is not suitable for contacts with varying lifestyles. This is not surprising since even a human being will not be able to track such a contact.

The call setup algorithm can be improved in various ways. For example, it can take into consideration seasonal changes. If the contact is a teacher, for example, s/he would not be working in the summer months, and so the daily call pattern would undoubtedly change. Another consideration which can be taken into account for further improvement is the tariff schemes. It is tedious for the ACR owner to have to input all his/her tariff schemes one by one. An alternative would be to download pre-formatted tables from a public server.

Apart from the software restrictions, a smart phone suffers from hardware limitations. The mobile phones battery is known to discharge faster when connected to a WLAN [10], whereas a cellular voice call's effect on battery life is lower. Hence, an ACMR user cannot stay connected to Wi-Fi all the time. Additionally the phone's middleware or operating system may not allow third party software access to certain functions such as automatic SIP VoIP call setup. This impedes the developer the implementation of certain ACMR features, such the handling of handovers.

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