A Tele-economic Approach for MNOs and Software Based M-VoIP Operators to Co-exist Using Game Theory

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Abstract—In recent years, the telecommunications industry has seen the emergence of software based Mobile VoIP (M-VoIP) operators who are rapidly rolling out cheap products and services to compete with incumbent Mobile Network Operators (MNOs). These new entrants do not have their own access networks but rather deliver their services seamlessly by largely exploiting incumbents' 3G (UMTS) networks and public Wi-Fi hotspots mostly using Session Initiation Protocol (SIP). In this paper, a novel tele-economic approach for co-existence of these two types of operators is proposed and compared with the traditional Mobile Virtual Network Operator (MVNO) approach. Game theory was used to determine the conditions under which M-VoIP operators and MNOs could coexist and compete (using the South African context as an example) in a market in which mobile subscribers belong to both. The Gambit tool was used to obtain the Nash equilibria by enumeration of mixed strategies which prove to be a win-win situation.

Index Terms—MNO, M-VoIP, 3G, Co-opetition

I. Introduction

Mobile VoIP services can be classified into two main types according to the way they are being offered and how they work. The first type requires that the subscriber first dials a designated go-between number before he can be connected to the desired destination. This service can be used with any type of mobile phone within a 2G (GSM) mobile network. The second type, a software based Mobile VoIP service, is considered in this paper in which users are required to download a small application onto their mobile phones. Subscribers to this service have the ability to place free peer-to-peer calls to one another, and also to make cheap calls to other destinations without first having to dial a go-between number. This service can only be accessed by using Internet-enabled smart phones through Wi-Fi and 3G (UMTS) networks.

In [1], Peters et al. refer to the long history of telephony networks dating back to the late 19th century when Alexander Graham Bell made the first voice call. These so called early networks were mere connections of wires from one private user direct to another. However, technological changes over recent years in the telecommunications sector have lowered cost barriers, which have enabled the entrance of software based M-VoIP operators in the application layer of TCP/IP stack [2]. This technological shift has brought many benefits to end users. Some of the primary benefits include the ability to make free or low-cost calls and the abolishment of roaming fees. However, these new developments have not been received well within the traditional Mobile Network Operators' (MNOs') circles. Due to the fear of loss of revenue, some MNOs have resorted to blocking calls originating from their own subscribers destined to the new entrants. A classic example is the case of *T-mobile vs Truphone* [3] in which a court ruled in favour of the new entrant [4]. In this paper we suggest an approach, which can bring harmony in the competitive telecommunications environment, whereby the problem of non co-existence between competing players is mainly caused by technological advancements and innovation. The incumbent (MNO) struggles to grasp the idea that the new entrant (M-VoIP operator), although competing within the same subscriber base and offering identical services, can actually bring more good than harm to their relationship for their mutual benefit.

Gambit, a library of game theory software and tools for the construction and analysis of finite and extensive strategic games [5], is used to model the interaction between MNOs and M-VoIP operators with the objective of proposing the best strategic Nash equilibria for the incumbents and new entrants to co-exist. The rest of the paper is arranged as follows: Section II describes the M-VoIP operator. In Section III, the South African regulatory and legislative environment is outlined. Section IV focuses on game theory and Nash equilibria, while section V presents the proposed game. The methodology is discussed in Section VI and the simulation results are presented and discussed in Section VII. The conclusion is presented in Section VIII.

II. THE SOFTWARE BASED MOBILE VOICE OVER INTERNET PROTOCOL OPERATOR

The wide availability of sufficiently cheap Internet bandwidth caused by the rapid development and deployment of new radio technologies, plus the increase of processor speeds and battery life of digital communication devices like smart phones and Personal Digital Assistants (PDAs), have made it possible for the introduction of innovative mobile based Internet telephony services. Software based Mobile Voice over Internet Protocol operators have exploited the fact that today's 3G networks and Wireless LANs already support Voice over Internet Protocol (VoIP). A typical software based Mobile Voice over Internet Protocol operator (M-VoIP) distributes for free, a small application to be installed onto cellular phones. This application enables subscribers to connect to dedicated servers. The established connection enables cheap telephone calls to be made and allows the bypassing of the traditional MNO's network all together by routing it via the Internet Protocol to the desired destination. These services run "over-the-top" of the existing subscribers' data-plan agreed upon with their respective Mobile Network Operators or Wireless Broadband Providers [6]. This means that users have to pay for the Internet access plus the actual Internet telephony call. A negotiated termination fee is then charged between the M-VoIP operator and MNO for call completion on each others networks.

III. THE SOUTH AFRICAN REGULATORY AND LEGISLATIVE CONTEXT

Figure 1 shows the South African telecommunications ecosystem.

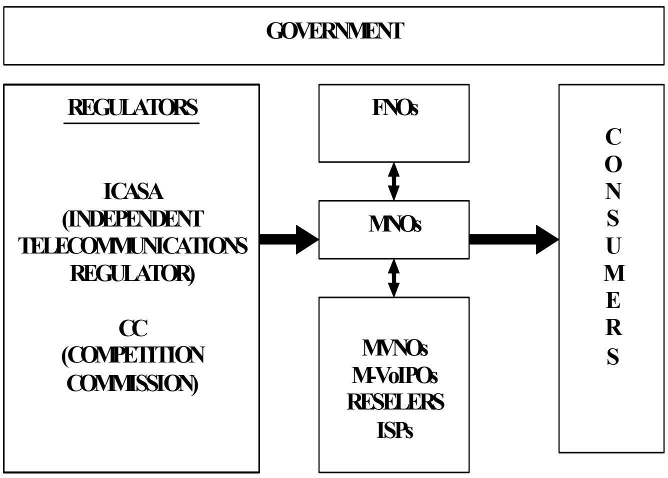

Fig. 1. The South African telecommunications ecosystem.

The South African mobile telephony industry comprises three MNOs, Vodacom, MTN, and Cell C, all of which own both 2G (GSM) and 3G (UMTS) spectrum licences. Vodacom controls slightly more than half of the local market [7]. Although South Africa has yet to formally legalize Mobile Virtual Network Operators (MVNOs), Virgin Mobile, Nashua Mobile, and Altech Autopage Cellular have been operating as MVNOs, under the guise of Enhanced Service Providers. The sector also includes Fixed Network Operators (FNOs) such as Telkom and Neotel, various resellers, and a number of Internet Service Providers (ISPs). Recently, software based M-VoIP operators have started to emerge on the local scene.

South Africa has already legalized VoIP [8]. Software based M-VoIP operators are categorized as Communication Services licensees. However, any potential interconnection negotiations are confined between the network operators only. This leaves unanswered the burning question of how the network-less Software based M-VoIP Operator can effectively co-exist with MNOs.

IV. GAME THEORY AND NASH EQUILIBRIUM

Game theory and the Nash equilibrium concept complement each other especially when one attempts to find the equilibria of a particular game. Many other methods of finding equilibria in game theory do exist but in this paper the focus is put on the concept of the Nash equilibrium because it is the most widely used concept.

A. Game theory

Game theory is a mathematical method of decision making in which a competitive situation is analyzed in order to determine an optimal course of action for the interested party. Depending on the players' interactions, game theory can be categorized into three main types: *Cooperative games*, in which players form coalitions without any conflicts; *Co-opetitive games*, in which self- concerned players form coalitions in a competitive situation; and *Non-cooperative games*, in which players are only self-concerned, i.e., concerned only about their own strategies [9].

B. Nash Equilibrium

The Nash equilibrium is a profile of strategies such that each player's strategy is the optimal response to the other players' strategy. Nash equilibria are consistent predictions of how the game will be played in the sense that if all players predict that a particular Nash equilibrium will occur, then no player has an incentive to play differently. Thus, a Nash equilibrium has the property that the players can predict it, predict that their opponent predicts it, and so on [10].

V. THE GAME

A multi-stage non-cooperative game is modeled in which we have two players: an MNO ("Player 1") which is large in size, owns a telecommunications network infrastructure and provides circuit switched based calling services; and an M-VoIP operator ("Player 2"), a small start-up which does not own any telecommunications network but can offer competitive cheap calling services to 3G and Wi-Fi enabled users through the MNO's network and Wi-Fi hotspots using innovative packet switched based technologies. The game has two stages: Stage 1, the initial phase, in which the MNO may over-invest in their 3G network and thus possess excess capacity; and Stage 2, the final phase, in which the MNO chooses its operating policy and decides whether to hike its

3G access network charges to the point that the new entrant (Player 2) cannot enter the market, or to decrease them and allow new entrants to enter the market. Player 2 enters the game in stage 2 and wants to exploit the MNO's subscriber base which comprises users with 3G and Wi-Fi capable mobile phones. Depending on how the MNO plays, Player 2 can offer services to either both 3G and Wi-Fi capable subscribers or to just Wi-Fi capable subscribers alone. It should be noted that in both cases, the MNO cannot prevent the M-VoIP operator from offering services to Wi-Fi capable subscribers since this option is facilitated through third party WLAN providers.

Figure 2 shows the MNO and the M-VoIP operator sharing the same subscriber database.

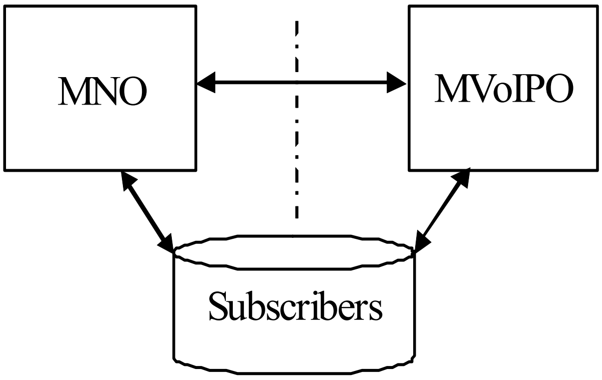

Fig. 2. MNO and M-VoIPO share the same subscriber base.

VI. METHODOLOGY

The equilibria presented in Equations (3) and (4) have been adopted from the work in [11], and are later modified in Equations (6) and (7) to depict the situation when Player 2 adds the Wi-Fi component. As already explained in Section V, the game begins when Player 1 invests in capacity k_1 at Stage 1 and then chooses output q_1 in Stage 2.

Let P denote the inverse demand price. The profile strategies for Player 1 in pure strategy space $S1$ are given by

$$s_1 = (k_1, q_1(k_1)), \quad (1)$$

where c is the cost, q is the quantity, k is the capacity, r is the extra cost per unit, D is demand and f is the entry cost.

Likewise, Player 2's strategies in pure strategy space $S2$ are given by

$$s_2 = (k_1, q_2(k_1)) \quad (2)$$

The payoff function that gives Player 1 a von Neumann-Morgenstern (vNM) utility u_1 for profile strategies s_1 and s_2 will then be:

$$u_1(s_1, s_2) = \begin{cases} (P)q_1 - cq_1, q_1 \le k_1 \\ (P)q_1 - cq_1 + r(q_1 - k_1), q_1 > k_1 \end{cases} \quad (3)$$

(vNM utility refers to the function that ranks the uncertain payoffs according to the highest expected value of the utility of the individual outcomes that may occur).

Likewise, the payoff function that gives Player 2 a von Neumann-Morgenstern (vNM) utility u_2, for profile strategy s_2 and s_1 will then be:

$$u_2(s_1, s_2) = \begin{cases} 0, q_2 = 0 \\ (P - (c + r))q_2 + f, q_2 > 0_1 \end{cases} \quad (4)$$

Since q_2 always depends on the value of k_1 , then Player 2's strategies are dominated by Player 1's for all $s_2 \in S2$

$$u_1(s'_1, s_2) > u_2(s_1, s_2) \quad (5)$$

From (1) to (5), it easily deduced that overall Player 2's level of competitiveness largely depends on Player 1's willingness to allow real competition because it does not invest into its own capacity but rather leases it [12]. Player 1 might easily decide to bar entry to Player 2 by setting $k_1 = q_1 D$ or can soften its stance and decide to allow entry but only doing so in a Stackelberg leader fashion. (Stackelberg refers to a strategic game in economics in which the leader firm (incumbent) has a crucial advantage of moving first and then the follower (new entrant) moves sequentially.). This scenario depicts the way traditional MVNO strategies are dominated by MNOs despite their all-out aggressive brand marketing campaigns. Intervention measures by relevant national regulatory bodies are essential to ensure the survival of MVNOs.

Equation (4) is modified by introducing the Wi-Fi component (denoted by the subscript "wi"); which then becomes:

$$c_2(q_2) = \begin{cases} 0, q_2 = 0 \\ (c + r)q_2 + f, q_2 > 0 \\ (c_{wi} + r_{wi})q_{wi} + f_{wi}, q_{wi} > 0 \end{cases} \quad (6)$$

Therefore, the payoff function in (6) changes to

$$u_2(s_1, s_2) = \begin{cases} 0, q_2 = 0 \\ (P - (c + r))q_2 + f, q_2 > 0 \\ (P - (c_{wi} + r_{wi}))q_{wi} + f_{wi}, q_{wi} > 0 \end{cases} \quad (7)$$

In this case, Player 1's strategies can never easily dominate Player 2's strategies and vice-versa due to the fact that their mutual playing ground is the 3G zone while at the same time innovative VoIP technologies allow Player 2 to play in the Wi-Fi segment which is free from Player 1's sphere of influence. Therefore for all $s_2 \in S2$

$$u_1(s'_1, s_2) \approx u_1(s_1, s_2) \quad (8)$$

VII. SIMULATION RESULTS AND DISCUSSION

Two rounds of simulations were performed using the following data set. In the first round of simulation, it was assumed that Player 1 has a 1/2 chance of investing in excess network capacity. If Player 2 is allowed access, the network will receive a vNM utility of 3: 1 for the data bundle sales and another 2 for the network externality effect caused by Player 2's free peer-to-peer calls offered in both 3G and Wi-Fi zones. Player 1 will lose a vNM utility of 3 whenever it denies entry to Player 2.

Player 2 will gain a vNM utility of 1 when allowed to access the 3G network and will always receive a vNM utility of 1 for supporting Wi-Fi capable devices. Player 2 will lose a vNM utility of 1 for not being able to access the 3G network. The second round of simulation is similar except that Player 1's chances of investing in excess capacity are 2/3 and 1/3 respectively.

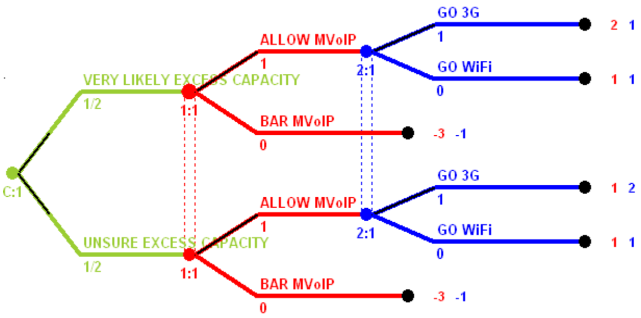

Fig. 3. The extensive representations of the game when MNO's chance to invest in excess network capacity = 1/2

Figures 3, 4, and 5 represent the first round of simulations. In Figure 3, the game tree shows that, after the chance move has been played the incumbent always decides to allow M-VoIP. This move indicates that barring M-VoIP is a less probable decision. Thus, the probability for the new entrant to access the 3G network is higher. Moreover, by default the new entrant uses Wi-Fi no matter what the outcome of the incumbent's decisions. In Figure 4, the strategic representation of the game indicates that the two Players' strategies; 1-2, 2-2, and 2-1, are either weakly or strictly dominated; strategy 1-1 is the exception. A bold cross means the strategy is strictly dominated while a dotted cross means that the strategy is weakly dominated. In Figure 5, all the dominated strategies have been removed from the game during the elimination rounds. In this game only one Nash equilibrium is found with the best strategy being 1-1 with a von Neumann-Morgenstern utility payoff of 3/2 for each Player.

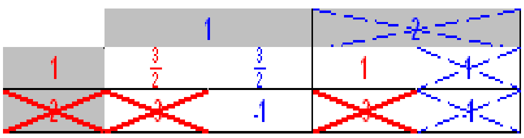

Fig. 4. A strategic form of the game depicting both Players' strictly and weakly dominated strategies when MNO's chance to invest in excess network capacity = 1/2

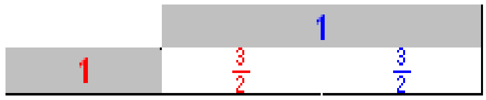

Fig. 5. A strategic form of the game after all dominated strategies have been eliminated when MNO's chance to invest in excess network capacity = 1/2.

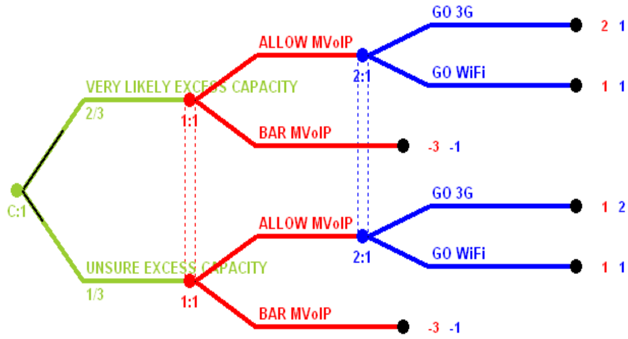

Fig. 6. The extensive representations of the game when MNO's chance to invest in excess network capacity = 2/3 and 1/3 respectively.

Figures 6, 7, and 8 represent the second round of simulations. It should be noted that, both Players' moves and counter-moves do not show any real signs of changes compared to the ones found during the first round of simulations when the MNO's chance of investing in the excess network capacity was 0.5. However, each Player's payoff for the dominant strategy 1-1 in Figure 8 has changed from 1/2 to become 5/3 and 4/3 von Neumann-Morgenstern utility values respectively. This demonstrates the possibility that MNO's decision makers are more likely to consider allowing M-VoIP when the chance of investing in excess network capacity is high.

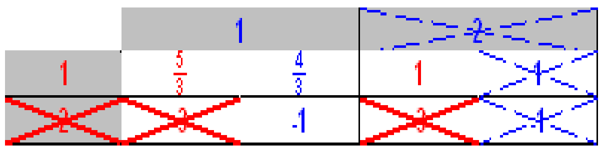

Fig. 7. A strategic form of the game depicting strictly and weakly dominated strategies when MNO's chance to invest in excess network capacity = 2/3 and 1/3 respectively.

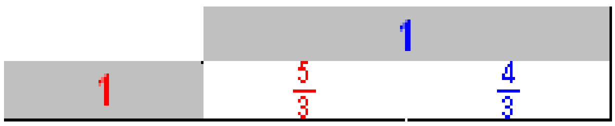

Fig. 8. A strategic form of the game after all dominated strategies have been eliminated when MNO's chances to invest in excess network capacity = 2/3 and 1/3 respectively.

The decision by the incumbent operator of whether to invest in excess capacity or not will mostly likely be influenced by the maximum traffic within the network and the amount of revenue generated. This is sufficient to show that the decision of whether to allow or deny the M-VoIP operator will also follow the same rule. However, the type of traffic and its usage pattern are the key indicators for determining when and which particular geographical area would need such an investment. On the other hand, should the M-VoIP operator be denied entry and decide to only use it's Wi-Fi segment, the externality effect will still be felt within the incumbent's network due to the variation and type of traffic because the two operators still share the same subscriber base. Despite all the complexities that are seem to arise, it is worth noting that these two operators, the MNO and M-VoIP operator, cannot play a zero sum game whereby one player can keep all the traffic to itself.

VIII. CONCLUSION

The results presented suggest that there is no need for the incumbent operator to block the new entrant, but rather should try to embrace it for their mutual benefit [13]. This approach will certainly bring the following benefits to the two players: The MNO will benefit from the positive network externalities effects caused by the cheap and sometimes free peer-to-peer calls offered by the new entrant, whereas the M-VoIP operator benefits come from the fact that it will be able to offer services to an expanded market of subscribers in both 3G and Wi-Fi segments.

This work did not take into consideration that Player 2 (M-VoIP operator) might decide to build its own telecommunications network infrastructure. Additionally, the Nash equilibria presented here are limited to non-cooperative games. Future work will concentrate on analyzing data captured from the real-life operators whereby the pure co-opetitive equilibriums will be further investigated.

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