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Benefits of mobile end user network switching and multihoming

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ABSTRACT

Mobile users have not been able to exploit spatio-temporal differences between individual mobile networks operators for a variety of reasons. End user network switching and multihoming are two promising mechanisms that could allow such exploitation. However these mechanisms have not been thoroughly explored at a general system level with QoE metrics. Therefore, in this work we analyze these mechanisms in a variety of diverse scenarios through a system level model based on an agent based modeling framework.

In terms of results, we find that in all scenarios end user network switching provides significant benefits in terms of both throughput and mean opinion score as the number of available networks increases. However, contrastingly, end user multihoming in most scenarios does not provide significant benefits over network switching given the same number of available networks. The major reason is inefficient radio resource allocation resulting from individual networks not taking the multihoming nature of end users into account. Though, in low user density situations this inefficiency is not a problem and multihoming does provide increased throughput though not increased mean opinion scores. Finally, scenarios that vary the fraction of users adopting multihoming suggests that both early and late adopters will have similar gains over users not adopting multihoming. Thus the adoption dynamics of multihoming appear favorable. Overall, the results support the applicability of end user network switching for improving mobile user experience and the applicability of end user multihoming in more limited situations.

1. Introduction

Mobile users increasingly expect an always-on high quality mobile connection regardless of their location. Mobile network operators (MNOs) have responded with technological advances such as LTE that have substantially increased connection throughput and reliability. However, so far, users have not been able to significantly exploit the temporal and spatial differences in quality between individual MNOs. This lack of exploitation partly results from the absence of widely available technical mechanisms, such as user driven national roaming or operator driven dynamic spectrum access, that allow such exploitation.

The absence of operator driven mechanisms is primarily a result of regulatory uncertainty and the significant business and technical complexity of such schemes. Whereas the absence of user driven mechanisms is primarily a result of operator resistance as such mechanisms often require low switching costs[1] which potentially threaten operators current business models.

Given this operator resistance, mechanisms that do not require operator support are particularly interesting. In that vein, end user network switching is a mechanism that does not require operator support because the network switching is assumed to occur completely on the end user device. In addition, the related mechanism of end user multihoming (an end user transmitting over several networks simultaneously and thus aggregating capacity) does not require operator support given a higher layer multipath protocol such as MPTCP. The two mechanisms are fully defined in Section 2.1.

Given the potential of these mechanisms, a key driver for spurring adoption is understanding the scenarios in which these mechanisms will benefit users and whether the actual user benefit is substantial. However, prior work [1–4] on these mechanisms has primarily focused on low level technical implementations rather than higher level system analyses. Furthermore, these technical works have not applied user-centric QoE metrics such as mean opinion score (MOS) in their analyses. Therefore, in this work we examine these two mechanisms through a system level model that applies an agent based modeling approach. The model provides several end user performance metrics (including throughput and MOS) for a variety of diverse scenarios including both technical and market conditions such as layout of base

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[1] The currently high switching costs (enabled by the entrenched MNO model in many countries) result in users switching MNOs at a timescale of years. This switching frequency is orders of magnitude too slow to significantly exploit the spatio-temporal differences between mobile networks.

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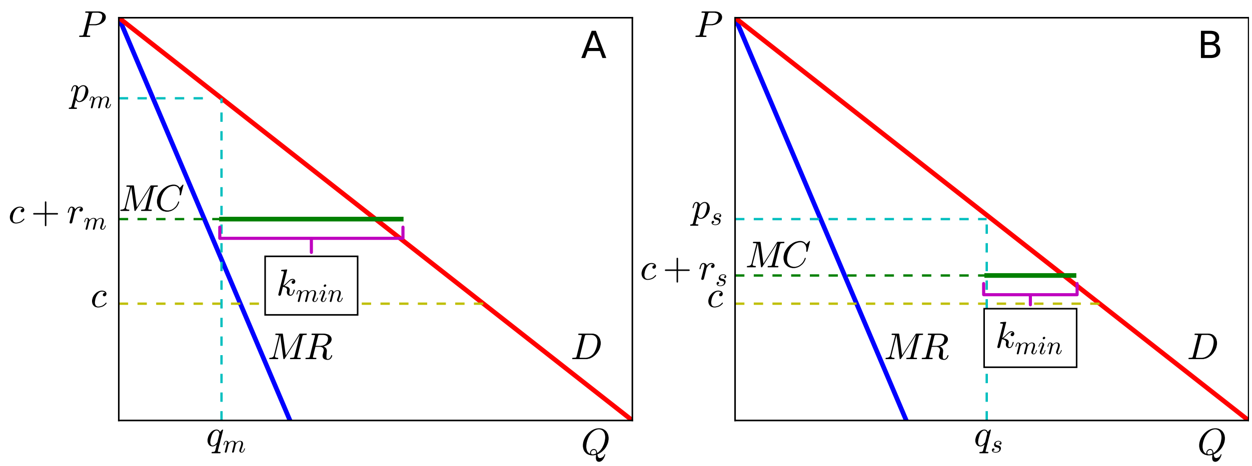

Fig. 1. Demand D (red), marginal revenue MR (blue), and long run marginal cost MC (green) curves under Spence-Dixit model illustrating: A) installed capacity q_m and market price p_m for the current situation given current k_{min} (minimum efficient scale), c is the marginal cost of production, r_m and $c + r_m$ are respectively the unit cost of capacity and the long run marginal cost of production which considers both production and capacity costs given macro cells B) installed capacity q_s and market price p_s given smaller k_{min}, c is the marginal cost of production, and r_s and $c + r_s$ are respectively the unit capacity cost and long run marginal cost given small cells. In both panes the axes are price P vs. quantity Q.

stations, user densities, and rates of adoption of the analyzed mechanisms.

Since these mechanisms can be adopted without operator support, non-MNO ecosystem stakeholders such as consumers, handset vendors, mobile platform owners, and regulators should be particularity interested in understanding the benefits of such mechanisms.

We briefly describe the structure of the remainder of the paper. Section 2.1 gives brief definitions of end user network switching and multihoming, Section 2.2 details the related concepts of network switching costs and small cell operators, Section 2.3 describes current related mechanisms in LTE, and Section 2.4 details related work. Section 3.1 introduces agent based models in general and Sections 3.2–3.5 describes the specifics of the agent based model we use in this work including the network assumptions and agent behavior. Section 4 presents the results of the different scenarios. Section 4.5 details the potential effects of the aforementioned network assumptions on our presented results. Finally Section 5 discusses the implications of results with a focus on regulators and Section 6 gives brief conclusions.

2. Background

2.1. Definitions

Due to the lack of standardized terminology in this area we give brief definitions of the two end user mechanisms we analyze in this work.

End user network switching: mechanism that allows a user to automatically and efficiently switch between mobile networks (with which the user has access through contracts) at a small timescale (scale on the order of seconds). The switching is performed entirely on the end user terminal and therefore no operator support is required.

End user multihoming: mechanism that allows a user to automatically, efficiently, and simultaneously use (transfer data over) several mobile networks (with which the user has access through contracts) thus aggregating network capacity. We assume that no information is shared between the networks (or between the BSs of the same network) about the multihoming nature of the users. This ensures that no operator support is required for end user multihoming.

Given these definitions we note that end user multihoming implies network switching to the extent that in end user multihoming the user simply selects the two best BSs (of all accessible to that user) to use simultaneously, whereas in end user network switching the user simply selects the best BS to use.

In terms of state of the art technical implementations of these mechanisms, [1] describes a network switching implementation for off-the-shelf Google smartphones based on the Google Fi MVNO[2] that has an average switching time of 8.8s and a potential lower bound switching time of 1.5s. While [2] describes a multihoming implementation for off-the-shelf smartphones over LTE and Wifi with near optimal aggregation performance. We note though that the lack of off-the-shelf smartphones with two LTE stacks prohibits the current implementation of multihoming over two LTE networks.

2.2. Switching costs and small cell operators

Economically, switching costs are defined as one-time costs that a buyer faces when switching from one provider to another [5] and these costs constitute an entry barrier since they determine the monopoly power of incumbent firms. If switching costs are high, an entrant firm should attract new customers by subsidizing the customers switching costs. When switching costs are low, competition is more dynamic and a new firm can more easily enter the market.

The reduction of switching costs can incentivize in some cases the entrance of new types of operators. Specifically if switching costs are low enough and end users can efficiently switch from one network to another, the minimum efficient scale of an operator decreases. For example, an entrant operator can offer network access only in localized pockets given the assumption that users can easily and efficiently switch to a wider area operator outside those pockets. Such cases are especially interesting for new network deployments such as small cells, M2M and more generally IoT. This new type of operator is known as a small cell operator or micro-operator.

From a competition perspective, according to Spence-Dixit capacity model [6,7], the industry installed capacity in a market can act as an entry barrier to new firms. Such a situation is depicted in Fig. 1A. Specifically, the industry installed capacity q_m is an entry barrier in a market if q_m is chosen such that the addition of the minimum efficient scale capacity k_{min} (by an entrant) would not be profitable. This minimum efficient scale capacity is the minimum size at which an entrant operator is profitable (can recover its average costs) due to

[2] Google Fi is a MVNO that aggregates three US MNOs (Sprint, T-Mobile, and U.S. Cellular) through dynamic switching of network SIM profiles.