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Channel Allocation Algorithms for Wireless Local Loops: Past Studies and Future Directions

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ABSTRACT

A wireless local loop connects customer premise equipment to the local exchange on the public switched telephone network using radio signals. Compared to wireline local loops, wireless local loops are easier to deploy and less costly to maintain. One of the most important considerations in deploying wireless local loops is to determine the best channel allocation algorithm. This paper provides an overview of channel allocation algorithms for wireless local loops, reviews previous related studies, and recommends several future research directions. The algorithm overview and research review can help IS researchers and IS practitioners gain a solid understanding of the channel allocation algorithms. The research directions can serve to guide interested IS researchers in future research.

Keywords

Wireless local loop, channel allocation algorithm, call overflow and repacking

INTRODUCTION

In delivering telecommunication services, a telecommunication provider must overcome the notorious “last mile” problem, which is “the final leg of delivering connectivity” (“Last Mile,” 2007, para. 1) from the local exchange to the telecommunication subscriber. Telecommunication providers today are under mounting pressure as more subscribers are demanding services such as high-speed and high-quality Internet access, video on demand, online gaming, and fast multimedia file transfer. Wireline networks, however, intrinsically lack flexibility, making them too time-consuming and cost prohibitive to upgrade. The existing wireline local loop infrastructure, therefore, is unable to meet the increased service demand, causing a bottleneck in the “last mile” (Clark, 1999). Moreover, there are roughly four billion people in the world earning less than $2000.00 USD annually and living in rural and remote areas (Gao, Quan, Jain, Kawahara, and Powell, 2004). Deploying the conventional wireline network for them is economically unfeasible.

A wireless local loop (WLL) connects customer premise equipment to the local exchange on the public switched telephone network (PSTN) using radio signals rather than copper wires or fiber-optic cables (Hung, Lin, Peng, and Tsai, 2004; Stavroulakis, 2003; Xiao, Zhang, Du, and Zhang, 2006). A typical WLL consists of a base station, a base station controller, and one or multiple subscriber terminals (Hung et al., 2004). A base station, combined with a base station controller, can serve multiple subscriber terminals that are within its radio coverage (Zhang, Xiao, Chen, and Hu, 2007). Each base station has multiple radio channels which serve as the communication channels. The base station controller handles the allocation of the radio channels; it is also responsible for transcoding the source code in the wireline network and in the air-interface (Satahack and Chayawan, 2004). Each customer premise equipment has a dedicated subscriber terminal, which is responsible for the wireless communication between the customer premise equipment and its corresponding base station (Hung et al., 2004; Zhang et al., 2007).

WLL offers several advantages over the wireline local loop. First, WLL takes less time to install and deploy as there is no need for digging ducts, setting up poles, or laying wires (Lee, 1998; Lin, 1997; Noerpel and Lin, 1998). Second, WLL is less costly to operate and maintain (Arora and Maskara, 2001). Third, WLL has greater flexibility both in bandwidth allocation and in geographical terms (Stavroulakis, 2003). Moreover, WLL can be easily extended, reconfigured, redeployed, adapted, and is distance insensitive (Lee, 1998; Lin, 1997; Sampson, 1996; Woo, 1999). With these advantages, the WLL has the potential to be an important alternative to its wireline counterpart, especially in developing, rural, or remote areas (Xiao et al., 2006).

Choosing a channel allocation algorithm from the several available algorithms is one of the most important considerations for a WLL. The choice will have significant impact not only on the WLL's implementation complexity but also on its performance (Hung et al., 2004; Xiao et al., 2006). The purpose of this paper is to provide an overview of the channel allocation algorithms for WLLs, to review previous related studies, and to recommend future research directions. We think that the algorithm overview, the research review, and the future research directions are both informative and useful to IS practitioners and IS researchers.

This paper proceeds as follows. In the next section, we explain each of the channel allocation algorithms for WLLs in detail. Next, we provide a review of previous studies concerning the channel allocation algorithms with an emphasis on two recent, important articles. After that, we recommend several future research directions in this subject. We conclude with a discussion of the implications of this study for both research and practice.

CHANNEL ALLOCATION ALGORITHMS

The channel allocation algorithms for WLLs include no repacking (NR), always repacking (AR), and repacking on demand (RoD). RoD has three subcategories, i.e., RoD – random (RoDR), RoD – least load (RoDL), and RoD – subscriber terminal (RoDST) (Hung et al., 2004). This section first briefly describes the WLL configuration and two important operations, i.e., overflow and repacking. It then explains each of the channel allocation algorithms in detail.

The WLL divides its service area into cells; each cell is served by a base station; and each base station, together with its base station controller, manages multiple radio channels (Xiao et al., 2006). A WLL can be single-tier, two-tier (e.g., macrocell and microcells), or three-tier (e.g., macrocell, microcells, and picocells), based on the configuration of the cells (Xiao et al., 2006) and the way the base stations are populated (Hung et al., 2004). In a single-tier WLL, no two cells fully overlap with each other; therefore, each subscriber terminal can be served by only one base station. In contrast, a two-tier or three-tier WLL overlays every large cell with several smaller cells (see Figure 1 for a three-tier WLL configuration); therefore, each subscriber terminal can be served by two or three base stations (Hung et al., 2004; Xiao et al., 2006; Zhang et al., 2007).

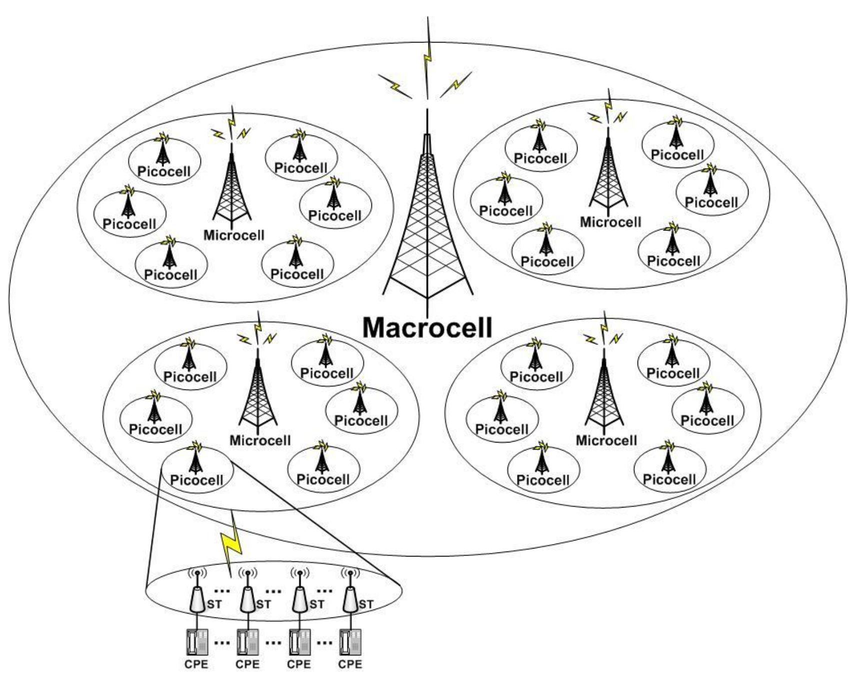

Figure 1. A Three-tier WLL Configuration

A multi-tier (i.e., two-tier and up) WLL performs overflow; and it may or may not perform repacking (Hung et al., 2004; Xiao et al., 2006; Zhang et al., 2007). Overflow is an operation that hands off a call from a lower-tier cell to the corresponding higher-tier cell; and repacking is an operation that hands off a call from a higher-tier cell to the corresponding lower-tier cell (Zhang et al., 2007). For a WLL to be able to perform repacking, at least one repacking candidate should be available (Xiao et al., 2006). A repacking candidate is a call that (1) occupies a radio channel of a higher-tier cell, and (2) the corresponding lower-tier cell of the call has an idle channel (Hung et al., 2004; Xiao et al., 2006; Zhang et al., 2007).

No Repacking (NR)

A WLL with an NR scheme does not perform repacking; it only performs overflow (Hung et al., 2004; Rappaport and Hu, 1994). When a new call arrives, a multi-tier WLL with an NR scheme always tries to allocate an idle channel in the lowest-tier cell (e.g., a microcell for two-tier WLLs or a picocell for three-tier WLLs) to the call. If some idle channels are found, the WLL assigns one of the idle channels to serve the call. Otherwise, the call overflows to the next adjacent higher-tier cell, and so on. Finally, if the WLL cannot find an idle channel for the overflowed call at the highest-tier cell (e.g., the macrocell for both two-tier and three-tier WLLs), then the call is blocked (Hung et al., 2004; Xiao et al., 2006; Zhang et al., 2007).

Always Repacking (AR)

A WLL with an AR scheme performs overflow; and it also performs repacking. More precisely, a WLL with an AR scheme always performs repacking as soon as a repacking candidate becomes available (Beraldi, Marano, and Mastroianni, 1996; Maheshwari and Kumar, 2000; Steele, Nofal, and Eldolil, 1990). A multi-tier WLL with an AR scheme always hands off a call in the higher-tier cell back to the next adjacent lower-tier cell as soon as an idle channel becomes available in the corresponding lower-tier cell (Hung et al., 2004; Xiao et al., 2006; Zhang et al., 2007). In doing so, AR keeps the maximum number of idle channels in the higher-tier cells (e.g., the macrocell for two-tier WLLs, and the macrocell and microcells for three-tier WLLs); intuitively, however, AR has the drawback of a high handoff rate (Lagrange, 1997).

Repacking on Demand (RoD)

Similar to AR, a WLL with RoD also performs both overflow and repacking. However, unlike AR, which performs repacking as soon as a repacking candidate becomes available, RoD performs repacking only right before a new call is to be blocked (Hung et al., 2004).

The overflow process of a WLL with a RoD scheme is identical to a WLL with an NR or AR scheme. The difference is that the WLL will try to perform repacking when the WLL cannot find an idle channel for the overflowed call at the highest-tier cell (e.g., the macrocell for both two-tier and three-tier WLLs). Repacking in a two-tier WLL is straightforward. If repacking candidates exist, the WLL will hand off one of the repacking candidates back to its corresponding microcell from the macrocell. Then the reclaimed macrocell channel is used to serve the new call. Otherwise, the new call will be blocked (Hung et al., 2004; Zhang et al., 2007).

Repacking in a three-tier WLL, however, is rather complex. According to Hung et al. (2004) and Xiao et al. (2006), the repacking steps are as follows. (1) The WLL checks whether there are repacking candidates in the macrocell. If yes, the macrocell picks one of the repacking candidates and hands it off to its corresponding microcell. The reclaimed macrocell channel is used to serve the new call. (2) If the macrocell fails to find a repacking candidate, the WLL checks whether there are repacking candidates in the corresponding microcell of the call. If yes, the microcell of the call will perform repacking, and the reclaimed microcell channel is used to serve the new call. (3) If the corresponding microcell of the new call fails to find a repacking candidate, the WLL checks whether there are repacking candidates among other microcells that also have call(s) being served by the macrocell channel(s). If yes, the WLL performs repacking first at that microcell, then at the macrocell, and finally allocates the reclaimed macrocell channel to serve the new call. (4) Otherwise, the new call is blocked.

The only difference between RoDR, RoDL, and RoDST is the way they choose the repacking candidates. In short, with RoDR, the base station controller randomly selects a repacking candidate for handoff; with RoDL, the base station controller selects the repacking candidate whose microcell or picocell has the least traffic load; and with RoDST, subscriber terminals make decisions of selecting repacking candidates for handoff upon a repacking request from the macrocell (Hung et al., 2004; Xiao et al., 2006).

PAST STUDIES

In the last decade, there have been numerous studies on the WLL and its channel allocation algorithms (Arora and Maskara, 2001; Gao et al., 2004; Hung et al., 2004; Lin, 1997; Noerpel and Lin, 1998; Stavroulakis, 2003; Woo, 1999; Xiao et al., 2006; Zhang et al., 2007). Because it is impossible to cover all previous related studies in such a short paper, we will concentrate on two recent studies which represent the latest research on this subject. One is Hung et al.'s (2004) analytic model and simulation study of the channel allocation algorithms for two-tier WLLs; the other is Xiao et al.'s (2006) simulation study of the channel allocation algorithms for three-tier WLLs.

In their paper, Hung et al. (2004) first developed an analytic model and then a simulation model to compare the performance of the different channel allocation algorithms (i.e., NR, AR, and RoD) in terms of the blocking probability *Pb* (defined as the number of blocking calls / [the number of successful calls + the number of blocking calls]) and handoff probability *Ph* (defined as the number of call handoffs / [the number of successful calls + the number of call handoffs]). They showed, with both the computation from their analytic model and results from their simulation experiments, that (1) RoD has the same *Pb* as AR, (2) AR and RoD have lower *Pb* but higher *Ph* than NR, (3) RoD has much lower *Ph* than AR when the WLL is engineered at *Pb* = 2%, and (4) RoDL has the lowest *Ph* among the three subgroups of RoD (i.e., RoDR, RoDL, and RoDST).

In their paper, Xiao et al. (2006) first presented and analyzed channel allocation algorithms for the three-tier WLL by using a decision-tree approach. They then investigated the blocking probability *Pb* and the handoff probability *Ph* of these algorithms by simulation. Their study showed that (1) given the same set of simulation parameters, NR has the highest *Pb*, AR has the lowest *Pb*, and the *Pb* of RoD falls in between, (2) compared with NR, both AR and RoD reduce *Pb* at the cost of a higher handoff rate, and (3) among RoDR, RoDL, and RoDST, RoDST has the lowest *Pb* but the highest *Ph*.

FUTURE DIRECTIONS

Drawing upon the overview of channel allocation algorithms for WLLs and the review of the previous related studies, we propose the following three future research directions, including (1) a comparison study, (2) quest for optimal *N*, and (3) impact analysis of mobile subscriber terminals.

A Comparison Study

Hung et al. (2004) did a simulation study of the channel allocation algorithms for two-tier WLLs. Xiao et al. (2006) did a simulation study of the channel allocation algorithms for three-tier WLLs. It would be interesting to do a performance comparison study of the different channel allocation algorithms between two-tier and three-tier WLLs.

Quest for Optimal *N*

A two-tier WLL can be obtained by overlaying the cells in a single-tier WLL. Similarly, a three-tier WLL can be obtained by overlaying the cells in a two-tier WLL. Using the same technique, an *N*-tier WLL can be obtained by overlaying an (*N*-1)-tier WLL. The promise of multi-tier WLL is more efficient channel utilization (Hung et al., 2004). However, when *N* gets larger, the complexity of WLL implementation may overtake the benefits that a multi-tier WLL can offer. An interesting research question might be the quest for the optimal *N* which can provide optimal performance for an *N*-tier WLL.

Impact Analysis of Mobile Subscriber Terminals

Although the WLL typically provides fixed-to-fixed connections (Woo, 1999), some argue that demand for mobility may "become greater once initial demand for basic fixed service has been fulfilled" (Swasey, 1998, p. 53). It might be interesting to study the impact on the performance of the WLL with the different channel allocation algorithms given that all subscriber terminals are mobile, e.g., they can move in all directions at a variety of speeds.

CONCLUSION

In this paper, we have provided an overview of the channel allocation algorithms for WLLs and reviewed previous related studies. Specifically, we described, in detail, Hung et al.'s (2004) analytic model and simulation study of channel allocation algorithms for two-tier WLLs, as well as Xiao et al.'s (2006) simulation study of channel allocation algorithms for three-tier WLLs. Furthermore, we have recommended three possible directions for future research.

The contribution of this paper is twofold. It provides IS researchers and IS practitioners an overview of the channel allocation algorithms for WLLs and a review of previous related studies which can help them gain a solid understanding of the subject. It also provides several research directions which can serve to guide interested IS researchers in future research.

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