行政院國家科學委員會專題研究計畫成果報告

無線區域網路資源分配法則之前瞻研究

Modeling Wireless Local Loop with General Call Holding Times and Finite Number of Subscribers

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主持人：林一平　　交通大學 資訊工程系

一、中文摘要

本計畫提出一個精確 (exact) 數學分析模型來計算有限用戶之無線區域迴路網路的通話遺失率。為了真實反應實際無線區域迴路系統的設計，我們設定基地台控制器與集線器間的幹線數目少於系統中的全部無線電通道個數。本數學分析模型已透過電腦模擬實驗加以驗證。此數學分析模型的執行效率較優於電腦模擬模型，然而時間複雜度卻高於幾個已被提出來的近似 (approximate) 數學分析模型。因此，我們在本計畫中設計了一個有效率的 (就時間複雜度與精確度而言) 無線區域迴路網路規劃程序。此程序先利用近似數學分析模型來將系統參數縮減至一個小範圍。接下來再使用我們的精確數學分析模型來從這個小範圍中準確地挑選適當的系統運作參數。我們的研究證明無線區域迴路之通話遺失和通話時間長度的分布無關，只和通話時間長度的平均有關。根據提出的數學分析模型，我們也列舉一些無線區域迴路的系統設計準則來避免資源瓶頸。

關鍵詞：無線區域迴路，通話遺失率，數學分析模型，電腦模擬模型，網路規劃程序

Abstract

This project proposes an analytic model to compute the loss probability for Wireless Local Loop (WLL) with a finite number of subscribers. The number of trunks between the WLL concentrator and the base station controller is less than the total number of radio links in the WLL. This model is validated against the simulation results. The execution of our model is efficient compared with simulation. However, its time complexity is higher than several existing analytic models that approximate the loss probability for WLL. Therefore, we design an efficient WLL network planning procedure (in terms of time complexity and accuracy) that utilizes the approximate analytic models to provide small ranges for selecting the values of system parameters. Our model is then used to accurately search the operation points of WLL within the small ranges of the system parameter values. This project proves that the performance of WLL with limited trunk capacity and finite subscriber population is not affected by the call holding time distributions. Based on our model, we illustrate WLL design guidelines with several numerical examples.

Key words: Loss probability, Engset product form, supplemented generalized semi-Markov process, wireless local loop

二、緣由與目的

Wireless local loop (WLL) provides two-way communication services to stationary or near-stationary users within a small service area. This technology is intended to replace the wireline local loop. In telephony, *local loop* is defined as the transmission circuits between a *Local Exchange* (LE) and *Customer Premise Equipment* (CPE). The trunks start from the LE in the local loop and are broken into several smaller bundles of circuits after some distance from the LE. These circuits are eventually separated into "drops" for individual subscribers. The cost of the local loop tends to be dominated by these drops on the end-user side, which is typically referred to as the expensive "last mile". This is particularly true for rural areas. The LE is typically the first point-of-traffic concentration in the *public switched telephone network* (PSTN), especially for older installations where, on the line side of the LE, all facilities from the line-interface card to the CPE are dedicated to a single telephone number. New installations connect residential neighborhoods or business campuses to the LE and use statistical multiplexers to concentrate traffic. However, the last few hundred yards of wiring from a residence to the statistical multiplexer in the local loop is always dedicated. Compared with the wireline local loop, WLL offers advantages such as ease of installation and deployment (installation of expensive copper cables can be avoided) and concentration of resources [1], [2].

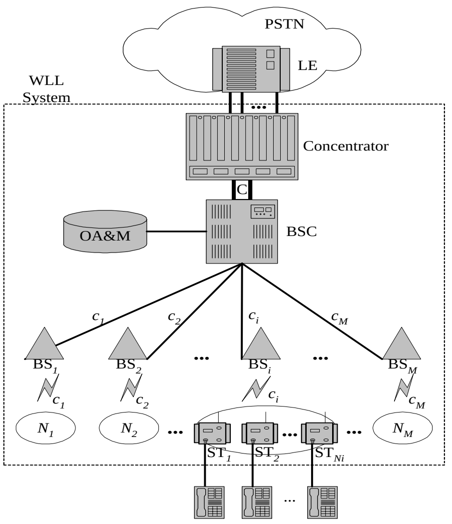

Figure 1. A Typical WLL Architecture

Figure 1 illustrates a typical WLL architecture [3], [4], [5], [6]. This WLL architecture consists of *Subscriber Terminals* (STs), *Base Stations* (BSs), the *Base Station Controller* (BSC), the *Concentrator*, and the *Operations, Administration, and Maintenance Center* (OA&M Center). These components are described as follows:

Subscriber Terminal: An ST is co-located with the CPE (e.g., telephone set), which is responsible for converting and delivering speech and control signals between the CPE (through the subscriber telephone line) and the corresponding BS (through the air interface).

Base Station: There are M BSs in the system. For $1 \leqq i \leqq M$, there are N_i STs in the radio coverage area of the ith BS. This BS is equipped with c_i radio channels and is connected to the BSC with c_i backhaul transmission lines.

Base Station Controller: The BSC controls the concentrator, BSs and STs to perform call setup and release between the PSTN and CPEs. The BSC connects to the concentrator with C trunks.

Concentrator: The concentrator performs concentrating and mapping functions between the subscriber lines to the LE and the trunk circuits to the BSC. The number of subscriber lines between the concentrator and the LE is equal to the number of CPE/STs in the WLL network (i.e., $\sum_{i=1}^{M} N_i$).

Operations, Administration, and Maintenance Center: The OA&M Center is responsible for operating, controlling, and monitoring the whole WLL network. An example of WLL OA&M design and implementation can be found in [7].

The performance of a WLL network is affected by the capacities of BSC (i.e., the number C of trunks) and BSs (i.e., the number c_i of radio channels). Since the simultaneous on-going calls in a WLL system are expected to be much smaller than the number of subscribers in the system, it is typical in network planning that

$$N_i > c_i \text{ and } C \le \sum_{i=1}^{M} c_i$$

To determine the C and c_i values, several models have been proposed to study WLL, including the Erlang-B formula [8], Engset-Syski (ES) model [9], and Erlang Product Form (EPF) model [10], [11], [12], [13]. These models either assume $C = \sum_{i=1}^{M} c_i$ (Erlang-B and Engset) or $N_i = \infty$ (Erlang-B and EPF). Therefore, they can only be used as approximate modeling of a general WLL system in a primary study.

In this project, we first investigate several approximate analytic models. Then, we propose an exact analytic model for general WLL systems where N_i ($1 \leqq i \leqq M$) are finite and $C \le \sum_{i=1}^{M} c_i$. We will validate our analytic model with the simulation experiments and investigate the time and space complexities of the model.

三、結果與討論

This project studied the performance of WLL systems with a finite number of subscribers and a finite number of trunks in the BSC. We investigated several approximate analytic models and proposed an exact analytic model to compute the loss probability of WLL. In deriving the stationary distribution of the system states for the exact model, we also proved that the loss probability for the WLL is insensitive to the call holding time distributions, and is only dependent on the mean of the call holding time. The exact model was validated against the simulation experiments. We observed that the time complexity of simulation is much higher than the exact analytic model. On the other hand, the executions of the approximate analytic models are much faster than that of the exact analytic model. We designed an efficient procedure (in terms of time complexity and accuracy) to identify the operation points of a WLL system. In this procedure, the approximate models are utilized to quickly compute upper and lower bounds for the engineered operation points of the WLL system parameters. Then the exact model is used to accurately compute the performance results for the values of input parameters in the ranges identified by the approximate models. The network planner then selects the appropriate values for WLL system parameters based on the outputs of the exact analytic model.

According to the exact analytic model, we illustrated some WLL design guidelines by numerical examples. We showed, for an arbitrary call traffic, how to identify the bottleneck resources of WLL, and how to appropriately increase the bottleneck resources to improve the WLL performance. Our guidelines are general enough to accommodate all kinds of call holding time distributions.

四、成果自評

1. 本計畫之研究成果已發表於 IEEE Transactions on Computers, Volume 51, Number 7, pages 775-786.
2. Propose an exact analytic model to compute the loss probability of a WLL system.
3. Prove that the loss probability for the WLL is insensitive to the call holding time distributions, and is only dependent on the mean of the call holding time.
4. Propose a simulation model to validate the exact analytic model.
5. Design an efficient procedure to identify the operation points of a WLL system.
6. Illustrate some WLL design guidelines by numerical examples. Our guidelines are general enough to accommodate all kinds of call holding time distributions.

五、參考文獻

[1] Lin, Y.-B. and Chlamtac, I. *Wireless and Mobile Network Architectures*. John Wiley & Sons, 2001.

[2] Noerpel, A. R. and Lin, Y.-B. Wireless Local Loop: Architecture, Technologies and Services. *IEEE Personal Communications*, Vol. 5, No.3, pp.74-80, 1998.

[3] Trotter, P. and May, A. Wireless Local Loop: Market Strategies. Ovum, 1996.

[4] Ericsson Com. DECT Access Node –DAN. Ericsson Business Networks, April, 1997.

[5] ETSI. Radio Equipment and System (RES): Radio in the Local Loop. Technical Report ETR 139, ETSI, Nov. 1994.

[6] ETSI. Radio Equipment and System (RES): Digital Enhanced Cordless Telecommunications (DECT): Services, Facilities and Configurations for DECT in the Local Loop. Technical Report ETR 308, ETSI, Aug. 1996.

[7] Huang, J.-Y., Tsai, H.-M., Lin, Y.-B., and Tseng, C. C. Design and Implementation of an OA&M System for WLL Network . *IEEE/KICS Journal of Communications and Networks*, Vol.2, No. 3, pp.266-276, 2000.

[8] Kleinrock, L. *Queueing Systems; Volume I: Theory*. Wiley, 1975.

[9] Syski, R. *Introduction to Congestion Theory in Telephone Systems*. Oliver and Boyd, 1960.

[10] Kelly, F. P. *Reversibility and Stochastic Networks*. John Wiley & Sons Ltd., 1979.

[11] Burman, D. Insensitivity in Queueing Systems. *J. Appl. Prob.*,

Vol.13, pp.846-859, 1981.

[12] Kelly, F. P. Blocking Probabilities in Large Circuit-Switched Networks. *Adv. Appl. Prob.*, Vol.18, pp.473-505, 1986.

[13] Dziong, Z. and Roberts, J. W. Congestion Probabilities in a Circuit-switched Integrated Services Network. *Performance Eval.*, Vol.7, pp.267-284, 1987.