An Applicable GSM Service Model for Rural Networking

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***Abstract*— Wide rural areas are often short of basic communication facilities and suffer from harsh geographic and climatic environments. Wireless networks which offer ease of operation and low maintenance cost appears to be a fast and feasible choice for service operators to install their individual networks.**

We first propose a refined wireless networking method to foster communication construction in rural areas. A one-pipe-four-layer wireless simulation model, called Service Model, is highlighted in the paper to implement the network planning method. The Service Model collects raw data from given rural areas and abstracts these data by flowing them through four technical layers to form the predicted technical wireless network. Thereafter, a software simulation environment, *BrwsLi,* is coded in freeware Scilab to realize the Service Model for the sake of instantiation. This simulation environment is able to set up a specified rural network by constructing topology for the network on the depicted areas, simulate the network traffic, and evaluate network performance and economic efficiency. The Newcastle region in KwaZulu-Natal of South Africa is chosen as the sample of real-world cases to demonstrate how to practically apply Service Model and present how to operate *BrwsLi* properly.

***Index Terms*— Scilab, modeling, rural communications, wireless.**

I. Introduction

Even though wireless telecommunication technologies have been showing considerable benefits for both urban and rural dwellers, it is more difficult to apply them technically and efficiently in telecommunications-raw rural areas than in urban areas with existing mature telecommunication infrastructures. Rural network planners therefore need a scientific rural-networks-modeling tool to make a blueprint of the communication networks for given rural areas.

A lot of substantial work has been done on rural communications to distribute appropriate services in unfavorable rural sites. Early in 1988, Nepal rural communication network was set up successfully by three stages, which are reconnaissance on the spot, network parameters analysis, and network construction [1]. This project succeeded in building a rural communication system for low-level developing countries by choosing the appropriate system and using the self-defined decisive parameters to construct a wireless network. However, since the project did not forecast the network either in a model or in simulation environments, it risked a failure of being a full-functional network. The simulations were done in CRCnet project performed by WAND group at the University of Waikato, Australia, in which simulation tools of Open source Squid Report Generator (SRG) and Distributed Arpwatch (Darpwathch) served as proxy analyzer and monitor separately [2]. However, the network encountered difficulties in acquiring enough available bandwidth and capacity because only WiFi was used in order to save money.

The proposed Service model in this paper aims to provide network planners with a simple and easily understandable theoretical model as to fundamental rural wireless networking. In the model, the steps on how to quickly put up a wireless network in rural areas are shown, and the reasons for doing so are given at the same time. The model is made visible and operable via the realization of an appropriate simulation environment, *BrwsLi*. The purpose of developing this software simulation tool is to visualize a planned network on the basis of the model and evaluate the network in a scientific way. Moreover, both the Service Model and the simulation environment can be used widely among areas within GSM/GPRS coverage and are applicable to CDMA in theory.

The general benefits of and requirements on networking in rural areas are described in [3]. This paper gives an example of modeling rural networks using GSM. The model has also been presented at the South African Telecommunication Networks and Applications Conference 2005 as well [4]. This paper is organized as follows. The theory of the Service Model is firstly brought out in details in Section II, and its application in Newcastle is explained in Section III by analyzing real data. Thereafter, Section IV designs a prototype for the Service Model, which gets implemented in Scilab language in Section V. The conclusions of the Service Model are stated in Section VI.

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II. SERVICE MODEL

A one-pipe-four-layer model, namely Service Model, is designed to simulate service-modeling for universal access (basic voice access) in rural areas [5]. At the top of the hierarchy, an Application Layer defines high-level services to be supported by the network. These services are interpreted by sub-services at the Guideline Layer, and each sub-service functions independently. Following behind the Guideline Layer is the Network Layer. In the Network Layer, the overall architecture and communication strategies of the system, such as network nodes configuration, routing and rerouting, are defined by considering the constraints imposed by the Application Layer and the interfaces provided by the Physical Layer. The Physical Layer can be found at the end of the hierarchy where it is responsible for supplying equipment and labor. The Management Pipe manages the four layers throughout the entire process of modeling. The relationship of the above pipe and four layers can also be visualized as a distilling water system in Fig. 1:

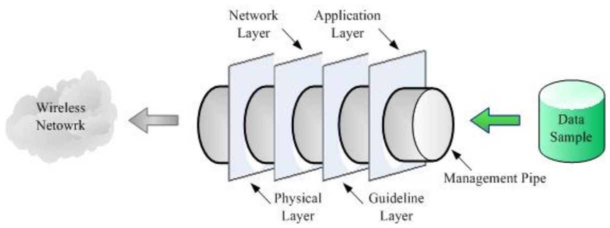

Fig. 1. Service model guide. First, one can conceive of the Management Layer as a pipe, the Application Layer, Guideline Layer, Network Layer, and Physic Layer then take their turns in this sequence, with each serving as a filter. After we have defined the input data and customer needs, data flows in the form of a stream through these filters one by one. In the end, we can get the "distillated running water".

The five functional entities of the pipe and layers are explained as follows:

A. *Management Pipe*

Management Pipe manages the four layers throughout the entire process of modeling in terms of the four system management aspects, which are functional requirement, operating system, system administration, and database [6]. The pipe is supposed to supervise the data in all layers, coordinate compatible parameters for each layer, maintain the upgrade of operating systems and application software, and adopt modular design to ensure scalability.

B. *Application Layer*

The first layer of the Service Model aims to clarify the types and characteristics of services that the wireless network is supposed to provide to customers, and is therefore called the Application Layer. The Application Layer is designed to help understanding the service requirements of the five communication nodes throughout the value chain, including telecommunication carrier, service provider, equipment manufacturer, information channel and end user [7]. A general relationship between them is depicted as Fig. 2:

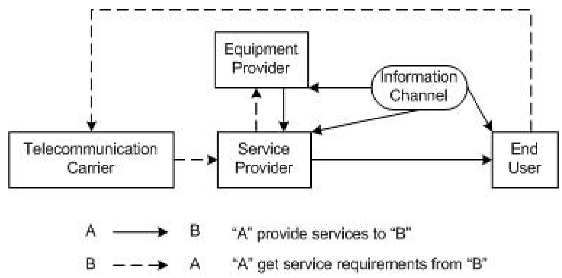

Fig. 2 Service chain in a communication network. There is an obvious relation of service-supply and service-demand between any two of the five communication nodes, so issues on service play a connective role in constructing a local network.

C. *Guideline Layer*

The Guideline Layer gives the criteria, for reference, as to resolving technical problems when constructing a rural wireless network. Thus, services in the Application Layer are specified in the Guideline Layer as detailed technical targets. For instance, the technical targets for constructing a rural wireless network include how to render a high-quality voice communication over long distance, or how to protect a network from natural interference. Two questions in the Guideline Layer are taken into main consideration:

1) How can we choose an appropriate wireless technology according to rural situations? Often high quality, large coverage, short rollout time, low initial and life-time cost, and strong social profits are used as threshold parameters for networking evaluation [8].

2) What technical parameters need considering in a rural network construction? The characters of Quality of Service (QoS), Bandwidth, Transmission Speed, Network Capacity and Signal Delay form the emphasis of technical problems in the Service Model in order to provide rural areas with universal wireless access [9][10].

D. *Network Layer*

Network topology in the Network Layer is used in conjunction with technology calibrations in the Guideline layer to build an ideal wireless network on paper. Ordinarily a network topology is characterized by 1) physical topology, representing the physical interconnection structure of a network graph, 2) routing algorithm, restricting the set of paths that signals or messages may follow, 3) switching strategy, prescribing how data traverses a route, by circuit switching or packet switching, 4) flow control mechanism, explaining when a message is allowed to traverse a route and what happens when traffic congestion is encountered.

E. *Physical Layer*

The Physical Layer forms a final physical platform that is responsible for setting up a wireless network. The apparatus

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involved with most commonly-used wireless network nodes in GSM include local exchange, base station controller, base station, and subscriber terminal [11]. To link these apparatus that have multifarious network purposes, transmission media materials vary in terms of their working parts in the whole network, including backhaul, access, and last miles. These transmission media materials are twisted pair, cable, fiber, microwave link, and satellite. When considering the most appropriate equipment for network settings in rural areas, what is always taken into account is the network availability (long distance and resultant interference) and economic cost.

III. NEWCASTLE APPLICATION

According to [5], a technical Newcastle-service-model has been set up by applying the one-pipe-four-layer service modeling theory to the health system of Newcastle, South Africa, which is called Newcastle-Health-System (NHS). The real-world application is specially applied to a rural South African community because South Africa has a very low level of communication infrastructure in rural and remote areas [12] with a high demand for voice communications and a steadily growing demand for data communications [13]. An operable networking in rural South Africa can be expected in other rural areas with similar communication status.

A. *Newcastle-service-model*

First, a bird's-eye view of the Newcastle-service-model was drawn [5]. Overall, the model aimed to provide wholesome medical treatment services to customers (all patients in NHS), both in rural centers or commercial farms and along three main roads in Newcastle areas, as shown in Fig. 3(a). A compound management mechanism of Central Information Management (CIM) and Distributed Information Management (DIM) was proposed in NHS according to the different service requirements of different network nodes. Optimal technologies, such as Global System Mobile 400 (GSM400), Global System Mobile/General Packet Radio System Network In a Box (GSM/GPRS NIB), were chosen under the communication background of South Africa, and seven parameters were selected to evaluate network efficiency, including network traffic "A", probability of call blocking "B", bandwidth "Bs", average link delay "E[T]", average route delay "Ts", network capacity "Cnw" and network efficiency "E". Moreover, a self-contained network topology was selected as shown in Figure 3(b), coupled with a Distance Vector routing algorithm (DV), a Time Division Multiple Access (TDMA) packet switching strategy and a non-congestion flow control mechanism. Finally the three main physical network nodes - Gateway (GW), Base Station Switching Node (BSSN) and Base Station (BS), were entered in the model on the basis of the self-contained network topology and special rural Newcastle environments.

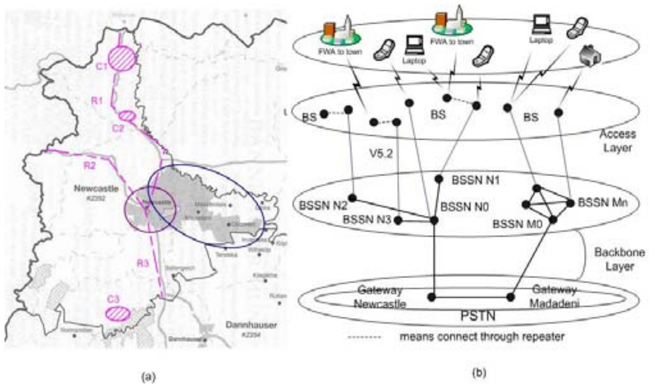

Fig. 3 Network topology of Newcastle-Health-System.

Furthermore, the formulae for calculating the *A*, the *B*, the *Bs*, the *E[T]* and the *Ts* are listed as follows [14][15]:

$$A = S \cdot \lambda \tag{1}$$

$$B = \frac{A - A_0}{A} = \frac{\lambda - \lambda_0}{\lambda} \tag{2}$$

$$B_s = 40 \cdot \alpha \cdot \beta \cdot C \cdot L \cdot \frac{1 + (a-1) \cdot p_e \cdot L}{1 - p_e \cdot L} \tag{3}$$

$$E[T] = \frac{1}{\mu} \cdot \frac{1}{1-\rho} \cdot \left(1 - \frac{\rho}{2}\left(1 - \frac{p_e \cdot L \cdot a^2}{(1 + (a-1) \cdot p_e \cdot L)^2}\right)\right) \tag{4}$$

$$T_s \leq 4 \cdot n_{av} \cdot \frac{L}{B_s} \cdot \frac{1 + (a-1) \cdot p_e \cdot L}{1 - p_e \cdot L} \tag{5}$$

Here A_0 is the successful incoming traffic in Erlang, S is the average occupying time of each call, λ is the number of calls per hour, λ_0 is the number of successful calls per hour, α is the fraction of the inter-node traffic, β is the traffic density (Erlang/km^2), C is the coverage areas (km^2), L is the number of bits for each signaling message, a is the window size of Go-Back-N (GBN) protocol [15] between messages, p_e is the bit error rate of the inter-connection links, μ is the processing rate of calls, ρ is the ratio of λ and μ, n_{av} is the average number of links for a successful path.

B. *Network Capacity Estimation*

After setting up the network, network capacity is chosen as the key parameter to evaluate network performance. A complex network capacity can be estimated in TABLE I and some assumptions to rural Newcastle will follow [5].

As is reported, there are 55,184 households in Newcastle area and each represents a user, and 56% of the Newcastle population lives in rural areas [16]. We assume that 80% of these rural people cluster around three rural centers: Hilda, Ingogo and Lookop, and travel along three main roads (refer to Figure 3.(a)). The average user traffic at peak hour in rural Newcastle is supposed to be 0.015 Erlang, which is half of that over all areas in [17]. It is also assumed that Newcastle town and the three main rural centers hold most of the traffic in rural Newcastle. What is more, 2% of the traffic is assumed to be blocked at each BS. This is reasonable because it is in line with a requirement of Grade of Service (GoS), which is no

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more than 5% in the network [18].

TABLE I
CAPACITY ESTIMATION IN NEWCASTLE

Name		Formula	Value	Mark
Total Area		(km^2)	1854.60	TA
Rural Area		$TA \times 80\% \quad (km^2)$	1483.68	TAN
Total User		Newcastle households	55,184	TU
Rural Users		$TU \times 56\% \times 80\%$	~ 24,722	nUR
Region	Hilda	$50\% \times PR$	~ 12,361	nHUR
Popu-	Ingogo	$52.5\% \times 50\% \times PR$	~ 6,490	nIUR
lation	Lookop	$47.5\% \times 50\% \times PR$	~ 5,871	nLUR
BSSN Number (rural area)		$BSSN\ 2 \quad 8 \times BS$	1	H
		$BSSN3/4 \quad 4 \times BS$	2	IL
		$BSSN5/6/7/8/9 \quad 0 \times BS$	5	R
BS Num	Hilda	$BSSN\ 2$	8	nHBS
Rural	Ingogo	$BSSN\ 3$	4	nIBS
Center	Lookop	$BSSN\ 4$	4	nLBS
Total BS Num		$8 \times H + 4 \times IL + 0 \times R$	16	nBS
BS channel		$4\ or\ 8$	4	nBSCh
Max Traffic / BS		$nBSCh \times 8 \times 0.7 \quad (Erlang)$	22.4	trBS
Ave Traffic / User		$(Erlang)$	0.015	trAV
Traffic Density		$(tr_{AV} \cdot n_{UR})/TAN \quad (Erlang/km^2)$	~ 0.2499	β
Probability of Capacity Rejected			2%	pb
NW Capacity		$tr_{BS} \cdot n_{BS} \cdot (1-p)/tr_{AV}$	~ 23,415	Cnw
Expected NW Capacity		n_{UR}	24,722	Ct
NW Efficiency		$C_{nw}/C_t = C_{nw}/n_{UR}$	~ 94.72%	NE
NE Hilda		$\frac{tr_{BS} \cdot nH_{BS} \cdot (1-p)}{tr_{AV}} \Big/ nH_{UR} \times 100\%$	~ 94.72%	EH
NE Ingogo		$\frac{tr_{BS} \cdot nI_{BS} \cdot (1-p)}{tr_{AV}} \Big/ nI_{UR} \times 100\%$	~ 90.20%	EI
NE Lookop		$\frac{tr_{BS} \cdot nL_{BS} \cdot (1-p)}{tr_{AV}} \Big/ nL_{UR} \times 100\%$	~ 99.71%	EL

"NW" stands for network, "#" stands for number.

As can be deduced from TABLE I, by applying a network to rural Newcastle, the communication requirements are met adequately and the network efficiency of the entire network is around 94.72%. Even the lowest local network efficiency is as high 90.20% in Ingogo. When the average user traffic is lower than 0.015 Erlang during normal time, the network efficiency is quite closer to 100%. Additionally, the user traffic assumption is reasonable because the user traffic density of 0.2499 is close to 0.25 that is the general assumption of user traffic density for rural areas [15].

IV. PROTOTYPE DESIGN OF SIMULATION

A simulation software environment, *BrwsLi*, was set up to initialize the Service Model. It was developed in Scilab, a freeware from INRIA with a Matlab-like syntax and facilitates simulation and modeling of systems [19], using the network construction in Newcastle as an example. Its system prototype design is illustrated as Figure 4:

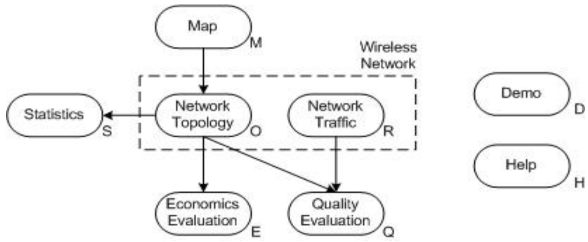

Fig. 4 Module of prototype design.

The system prototype design was developed as eight main functional modules. After drawing the map "M" of the specified area with a detailed distribution of the rural regions, the physical structure of the wireless network "O" can be developed. Meanwhile the daily network traffic "R" can be assumed. Initially, the wireless network topology and traffic are simulated, and then the network is evaluated in terms of both the network quality aspect "Q" and the network economy aspect "E". The network nodes and their relations can be viewed in the statistical database "S". Finally, the whole construction and evaluation procedure is exemplified in the demonstration "D" and some wireless theories and formulae are given in help item "H".

V. SIMULATION RESULTS

In this section, a general procedure of building the blocks of "O", "R", and "Q" in Figure Four for a wireless network is described in detail with a focus on the technical aspect of network construction.

A. Constructing a network

The user may construct the network topology from the Main Menu. He/She may change any available network node to obtain a final Newcastle network topology as has been given in Fig. 5 where the theoretical rural areas are covered or overlaid with minimum network equipment.

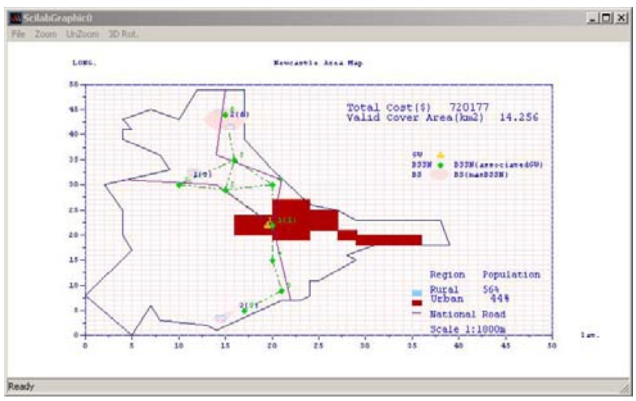

Fig. 5. *BrwsLi* - Newcastle network topology.

In *BrwsLi*, three main network objects are assumed in a self-contained network. These are Gateway (GW), Base Station Switching Node (BSSN) and Base Station (BS). Four operations of "insert", "delete", "move" and "update" are

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adopted to manipulate these network objects. Any operation can operate any network object.

B. Simulating network traffic

Following the topology construction of the Newcastle wireless network, network traffic is simulated. This is done on condition that the network is observed 8 hours a day, 280 calls arrive at a Poisson distribution in the observing hours and the call holding time is distributed exponentially [15], on average 6 channels are available at a time, and the mean call duration is 3 minutes. The reason for choosing these parameters is that "8 hours" is the most common number of business hours. The assumption that calls arrive at Poisson distribution and they hold at Exponential distribution is also widely used in a call traffic model [20]. The mean call duration that is supposed to be "3 minutes" follows most of the statistical data in [21]. Notably "6 channels" means an average proportion of occupation of channels. For example in a network with two BSs, one BS supplies a 4-channel capacity while another one provides 8 channels at the same time. Therefore, their average channel occupation is 6 channels. Thus, having taken all assumptions into considerations, the simulation results can be obtained in the following two figures [5]:

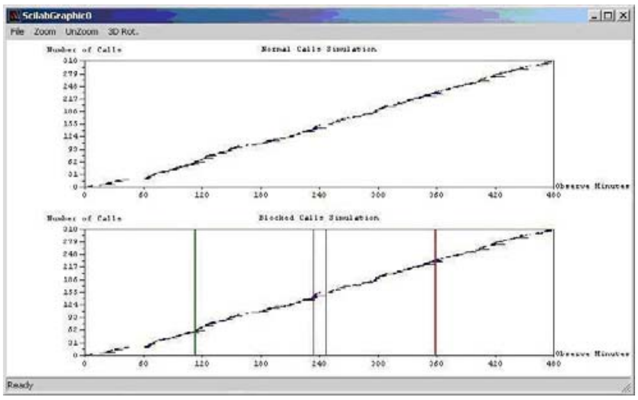

Fig. 6. *BrwsLi* - Traffic Simulation Results (Situations).

The figure in the upper part of Fig. 6 shows a simulation situation of general telecommunication network traffic on the basis of the above network conditions. The figure in the lower part of Fig. 6 shows that 3 calls out of 280 calls are blocked when 6 channels are fully occupied.

Moreover, in Fig. 7, the completed traffic, which is 1.8458333 Erlang, is achieved after having accumulated these simulated calls, and will be used in the following network quality assessment. The block probability or the GoS of 0.0093275 is smaller than 0.01, which is the threshold target that a network operator wants to meet [18]. Busy Hour (BH) from the 415th minute to the 474th minute and its Busy Hour Call Attempt (BHCA) of 1.8666667 Erlang are shown to help the network planner know more about network traffic states. It is noted that the traffic in busy hour is higher than the average completed traffic and it is universally acceptable.

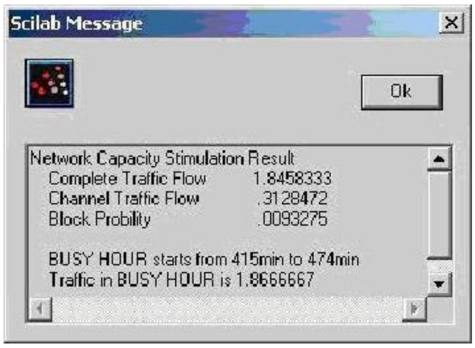

Fig. 7. *BrwsLi* - Traffic simulation results (Network capacity)

C. Appraise network quality

After having implemented network topology and network traffic, the self-contained network is ready for technical appraisal. Average link delay, E[T], is chosen for this paper for the analytical demonstration of network performance.

Necessary preliminary parameters of calculating E[T] are prepared beforehand. Some of them are determined by network topology. Assume that the Go-Back-N queuing mechanism (GBN) is used for call process [15]. Then the window size used in GBN between two BSSNs "a", the average number of links of a successful path "nav", the number of total links "nt" and service area "C" are determined by the network topology. Other preliminary parameters that are determined by network traffic include completed incoming traffic flow "A" and mean call duration "MeanCallDur". The rest of the preliminary parameters are assumed for rural network planning, including the number of messages for negotiating "nne", the ratio of call-arrival-rate to call-service-rate "ρ". It is noted that the calculated traffic density "β" is 0.1294776 Erlang/km^2 as a result of network traffic and coverage area. The value is less than 0.25 Erlang/km^2 that is normally assumed for rural areas [15], so the assumed network traffic is reasonable when "C" is fixed. Other parameters such as the product of bit-error-rate (BER) and message length "pe*L" are supposed to be filled in manually by the user. Here, the calculation result of the average link delay is addressed in Fig. 8:

As can be obtained in Fig. 8, when the rate of incoming calls is very low, the average link delay increases slowly. The nearer the call-arrival-rate reaches the call-service-rate, the more the increased amount of the average link delay per unit of "ρ". If the expected link delay is entered as a positive digit, for example "2", a line which represents the value of expected link delay will overlap with the inclination curves of the different pe*L. For instance, when the expected link delay is set to 2 as shown Fig. 8, a theoretical "ρ" shall be 0.5 if pe*L is 0.04. It can also be 0.6 if pe*L is 0.01.

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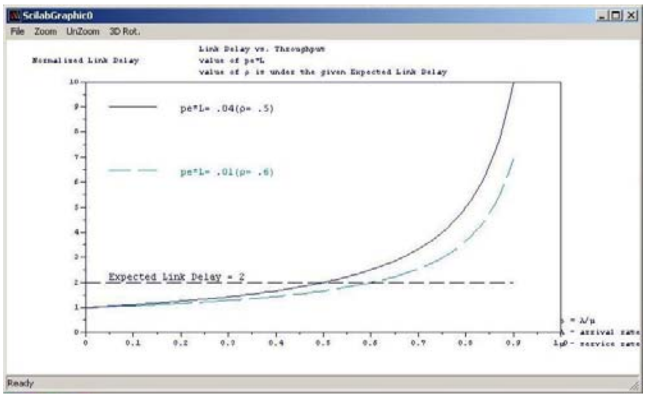

Fig. 8. ***BrwsLi*** **- Average link delay result. The x axis indicates the ratio of call-arrival-rates to call-service-rates, and the y axis indicates in seconds the average link delay. To be more detailed, in the x axis, the call-service-rate is estimated at 1 call per unit time, the call-arrival-rate ranges from 0 to 1 call per unit time. The relationship between the average link delay and the division of call-arrival-rates to call-service-rates is drawn under different products of bit-error-rate and message length (pe*L).**

VI. CONCLUSIONS AND FUTURE WORK

Rural communication industry has been marginalized for a long time because of little attention from government, expensive initial investment, and low return to the investors. The communication industry has actually become the bottle neck of local economy in rural areas despite its positive effect to other industries in urban areas. Yet there does exist a huge potential telecommunication market in fast-developing rural areas, where people have strong wish to communicate with people in other areas and are able to pay for that the services [3]. Meanwhile, the advances of wireless technologies to serve wider areas at acceptable price help to foster the development of wireless communications in rural and remote regions. The key challenge now is how to develop wireless communication in rural areas appropriately.

This paper proposes an applicable Service Model and an easily operable modeling environment, *BrwsLi*, to help one to plan, construct, simulate and evaluate an applicable wireless network in a systematic and simple way, encouraging the development of wireless communication networks in rural areas. Owing to the popular layer concept on which the Service Model is based and the convenient acquirement of Scilab, a set menu of the Service Model and *BrwsLi* simulation environment is prone to be widely used in rural network planning.

Future work may improve the above model. It is desirable to include into the system design interferences from the topology and weather in rural areas. In addition, the shortest-path-algorithm used in *BrwsLi* has considered only one aspect of QoS routing metrics [22] to determine the "best" route between the source node and the destination node. The accuracy of the evaluation result of network quality is then diminished because other aspects of QoS routing except hop-count have not been considered. After the interferences are taken into account and a better routing algorithm is used in the future research, the simulation environment will be more powerful and applicable.

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