

Modeling for Rural Networks Planning

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Abstract— With the advances in telecommunication information technologies, wireless industry has been showing extraordinary advantage in all aspects of human life. Particularly in open rural areas which are short of basic communication facilities and suffer from harsh geographic and climatic environments, the adoption of easy-operating and cheap-maintaining wireless communication appears to be a fast and feasible choice for telecommunication carriers and service providers to lay down their own networks. Profit is being made or expected with certainty from the potential telecommunication market in rural areas. Hence we embarked upon finding a refined wireless network planning 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 designed and 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 invented areas, simulate its network traffic, and evaluate the network performance and economic efficiency. What's more, Newcastle in KwaZulu-Natal, South Africa is chosen as the sample of real-world cases to demonstrate the way of applying the Service Model practically and present the way of operating *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 difficult to apply them technically

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efficiently in telecommunications-raw rural areas than in urban areas with existing mature telecommunication infrastructures. At this rate, a scientific rural-networks-modeling tool is expected by rural network planners to make a blueprint of the communication networks for given rural areas before these networks are set to be built.

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 - 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 of constructing 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 at low cost. In the model, the steps on how to put up a wireless network in rural areas quickly 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 is applicable to CDMA in theory.

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 and future work of the Service Model are finally stated in Section VI.

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 [3]. 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 or the interfaces provided by the Physical Layer. The Physical Layer can be found at the end where it is responsible for supplying equipment and labor. The Management Pipe manages the four layers throughout the entire process of modeling in terms of system management aspects. The relationship of the above pipe and four layers can also be visualized as a distilling water system in Fig. 1:

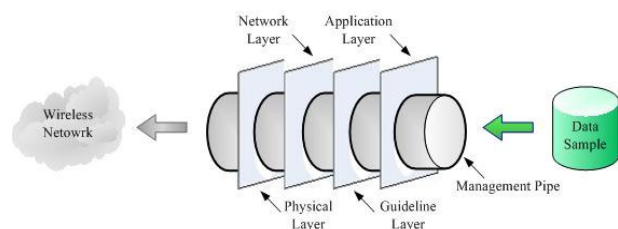


Fig. 1. Service Model Guide. First, one can conceive of the Management Layer as a pipe, the Application Layer, Guideline Layer, Network Layer, and Physical Layer then take their turns in this sequence, with each serving as a filter. After we have defined the input data and customer needs, data flows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

The five function 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 [4]. 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 [5]. A general relationship between them is depicted as Fig. 2:

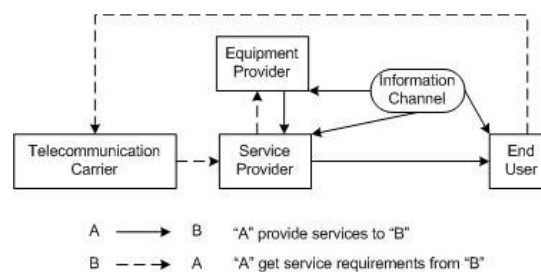


Fig. 2. Service Chain in a Communication Network. There is an obvious relation of service-supply and service-demand between any two of the five communication nodes, so issues on service play an connective role in constructing a local network.

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 factors in 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 [6].

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 [7]-[8].

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 involved with most commonly-used wireless network nodes in GSM include local exchange, base station controller, base station, and subscriber terminal [9]. 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 [3], 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 purpose of the model is to develop and implement an innovative community wireless network. 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 [10] with a high demand for voice communications and a steadily growing demand for data communications [11]. 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 [3]. Overall, the model aimed to provide customers (all patients in NHS), both in rural centers or commercial farms and along three main roads with wholesome medical treatment services 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 Fig. 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.

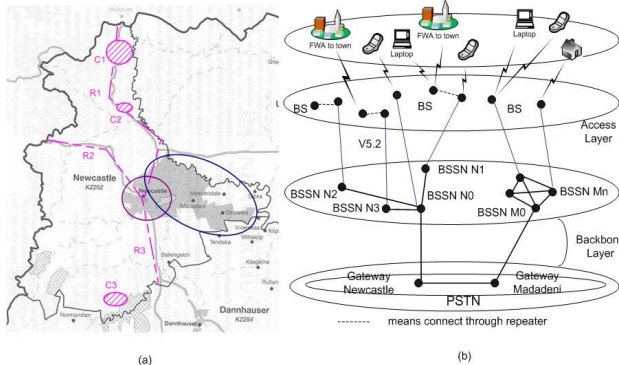


Fig. 3. Network Topology of Newcastle-Health-System.

Furthermore, the formulae for calculating the A , the B , the B_s , the $E[T]$ and the T_s are listed as follows [12][13]:

$$A = S \cdot \lambda \quad (1)$$

$$B = \frac{A - A_0}{A} = \frac{\lambda - \lambda_0}{\lambda} \quad (2)$$

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

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

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

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/km²), C is the coverage areas (km²), L is the number of bits for each signaling message, a is the window size of Go-Back-N (GBN) protocol [13] 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 [3]:

TABLE I
CAPACITY ESTIMATION IN NEWCASTLE

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

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

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 [14]. We assume that 80% of these rural people cluster around three rural centers: Hilda, Ingogo and Lookop, and travel along three main roads (see Fig. 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 [15]. 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 more than 5% in the network [16].

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 [13].

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 [17], using the network construction in Newcastle as an example. Its system prototype design is illustrated as Fig. 4:

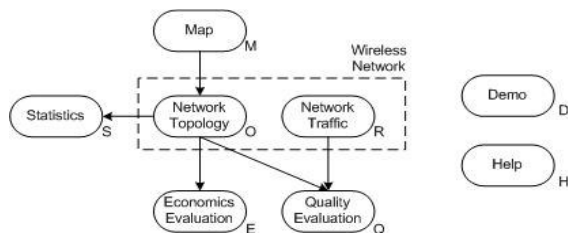


Fig. 4. Module of Prototype Design.

The system prototype design was developed as eight main function 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 Fig. 4 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.

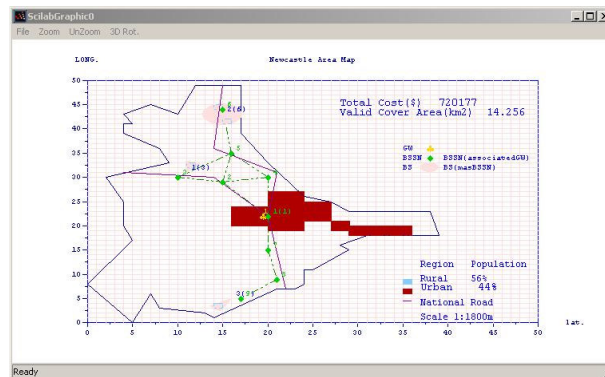


Fig. 5. *BrwsLi* - Newcastle Network Topology.

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 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 [13], 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 [18]. The mean call duration that is supposed to be “3 minutes” follows most of the statistical data in [19]. 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 [3]:

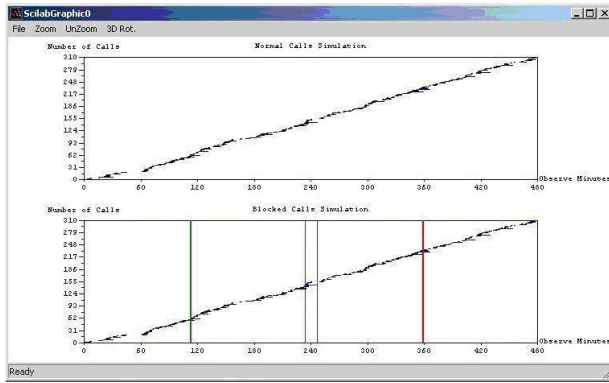


Fig. 6. *BrwsLi* - Traffic Simulation Results (Situations)

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 three calls out of 280 calls are blocked when 6 channels are fully occupied.

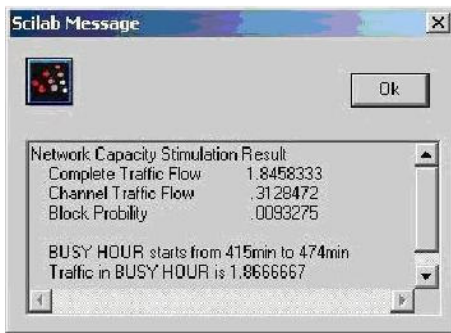


Fig. 7. *BrwsLi* - Traffic Simulation Results (Network Capacity)

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 [16]. 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.

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 [13]. 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/km² as a result of network traffic and coverage area. The value is less than 0.25 Erlang/km² that is normally assumed for rural areas [13], 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:

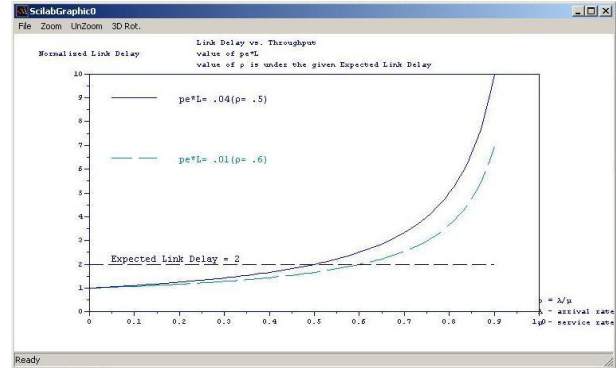


Fig. 8. *BrwsLi* - Average Link Delay Result. The x axis indicates the ratio of call-arrival-rates to call-service-rates, and the y axis indicates in seconds the average link delay. To be more detailed, in the x axis, the call-service-rate is estimated at 1 call per unit time, the call-arrival-rate ranges 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).

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 in 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.

VI. CONCLUSIONS AND FUTURE WORK

For a long time, rural communication industry has been marginalized due to less attention from government, expensive initial investment and little return to the investors. The communication industry has actually become the bottle neck of local economy in rural areas in spite of its positive effect on other industries in urban areas. However, 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 become able to pay for that. The advances of wireless technologies to serve wider areas at acceptable price can help to foster the development of wireless communications in rural and remote regions. At the moment the key challenge 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 introduce how to plan, construct, simulate and evaluate an applicable wireless network in a systematical and simple way, which will successfully encourage 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.

Though most parts of the system design have been achieved, there are still a few necessary functions that have not been accomplished and some valuable parameters have been omitted due to the limited time and labor. The most important network parameter that is not included in the system prototype design is interferences from the rough topology and weather in rural areas. Another parameter - the shortest-path-algorithm, which considers only one aspect of QoS routing metrics [19], was partially used in *BrwsLi* to determine the "best" route between the source node and the destination node. This has diminished the accuracy of the evaluation result of network quality due to not considering other aspects of QoS routing except hop-count. Once all the omission is worked out in the future research, the simulation environment will be more powerful and applicable.

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