Quantitative Comparison of Radio Environments for T-Ring Test System

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Abstract. T-Ring is a new integrated wireless testbed developed for scalable and reproducible evaluation and simulation of various wireless networks. Since it spans a large geographical area, the effect of signal propagation is truly real, which is a key required feature for some wireless research. For the purpose of comparing experimental results of T-Ring with similar experiments conducted on other real-world networks, quantitative comparison of the radio environments is imperative. This paper introduced a comparison method by calculating the similarity degree of the CDFs of a specific characteristic of two radio environments. Also we propose an expression of synthesized similarity degree which is a linear sum of similarity degree value of different channel characteristics. The comparison in this paper are currently made from the aspect of RSSI and RMS delay spread because of their close relation with large-scale fading and small-scale fading respectively. The contribution of each characteristic to the synthesized similarity degree is analyzed and the process of determining the weight factor of each characteristic with a pure simulation is presented. The numerical result demonstrates the feasibility of the comparison method and also shows that RMS delay spread is more effective than RSSI to show the difference of radio environments for cells with same or different sizes.

Keywords: quantitative comparison, radio environments, testbed, T-Ring.

1 Introduction

Real-world wireless network testbed has been always attracting significant attention from industry and from the research community. Most mobile wireless network research today relies on simulation. However, fidelity of simulation results has always been a concern, because simulations depend on the simplified models that do not capture real physical effects. So wireless network testbeds are necessary. However, because of the difficulty and high cost in building a full-scale testbed, most reported testbeds are simplified to some extent. For example,

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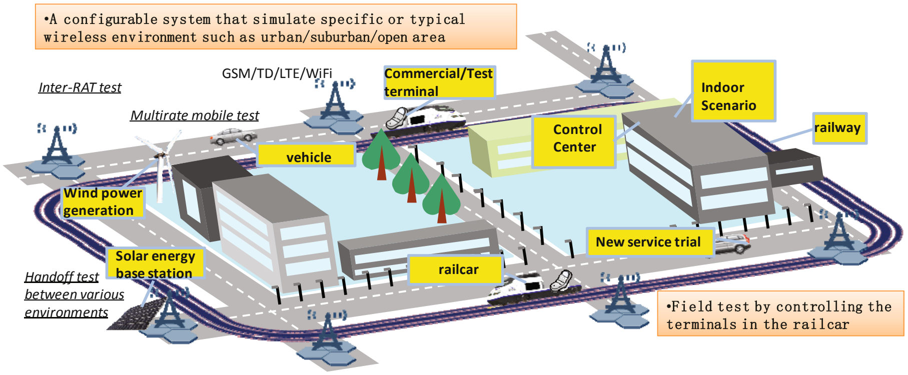

Fig. 1. General view of T-Ring system

MiNT testbed is a miniaturized one that can be deployed on a table [1]. But it inevitably encountered some problems to capture the effect of some physical effects such as node mobility and multipath fading. For this reason, there are still some full-scale testbeds reported, such as ORBIT Radio Grid Testbed [2] and APE [3]. They are all tailored toward specific applications and research areas such as Ad hoc network.

1.1 T-Ring Project Motivation and Overview

T-Ring project is a new integrated wireless testbed [4]. The key feature of the testbed is that it has a ringlike railway to carry the terminals, hence the name T-Ring. Not only will it be developed for wireless research, but it will also be used to support some industrial requirements such as field test. It is known that field test plays an important role to ensure the network quality during the construction and maintenance period. However, the performances of networks deployed in different regions sometimes differ widely because signal propagations are affected by the geographical environments etc. Therefore a testbed with real-world settings is needed to evaluate the performance of wireless network protocols and to help investigate some field test problems. These considerations motivated the T-Ring project. It aims to provide a flexible and scalable experimental facility for field test and research on heterogeneous mobile networks.

T-Ring testbed spans a large geographical area and has a real-world setting. The wireless signal can be received over a large radius of the order of several hundreds or even thousands meters. T-Ring consists of several kinds of environments and can be managed to approximate some specific radio environments to help investigate field test problems. The railway in T-Ring is used to carry the terminals. It ensures the reproducibility of the experiments and makes it easy for operators to control the mobility of the terminals, which is a bottleneck for other simplified testbeds. The general view of T-Ring is illustrated in Fig. 1.

1.2 Requirement of Quantitative Comparison of Radio Environments

For some specific requirements, T-Ring should has the ability being configured properly to approximate some specific radio environments. Operators can achieve the approximation by changing the positions of the base stations, adjusting the transmission power or adjusting altitude, tilt and directions of antennas. The mobility of user terminals can also be accurately controlled to capture the Doppler effect. An essential prerequisite for that management is the radio environment evaluation. Radio propagation environments are conventionally classified into urban, suburban and open areas etc. But those are not enough for T-Ring which needs not a qualitative but a quantitative evaluation. Moreover, the cells of T-Ring are distributed over a finite area while the realistic ones may possess different sizes and some of them are very large. So comparisons between cells with different sizes are necessary.

In this paper we will introduce a comparison method of radio environments with the definition of *similarity degree. similarity degree* is used to describe the relations of any characteristic of two environments. Furthermore, we propose an expression of *synthesized similarity degree* which is a linear sum of similarity degree values of different channel characteristics. Consequently a method of determining the weight of each characteristic in the synthesized similarity degree is produced. The comparison in this paper are currently made from the aspect of *received signal strength indicator* (RSSI) and *root mean square* (RMS) delay spread because of their close relation with large-scale fading and small-scale fading respectively. Some large-scale propagation study can help analyzing the coverage situation of the radio signal for various carrier frequency [5][6]. Meanwhile, this paper focuses on multipath effect for its tight relationship with the small-scale fading. There are lots of illustrations about multipath measurement [7][8][9]. To describe the multipath quantitatively, RMS delay spread is selected to be involved in the analytical evaluation. It should be pointed out that the comparison method can be extended to involve more radio parameters in future work.

2 Comparison of Radio Environments

For quantitative comparison and evaluation of radio environments, we should first decide which kind of radio characteristics should be used for comparison. In this section, we present the comparison from aspects of RSSI and multipath effect which are related with large-scale fading and small-scale fading respectively. RSSI depends on path loss effect and transmission power of the base station. The small-scale fading can be quantitatively described from several aspects [10]. RMS delay spread is used here to describe the multipath effect. Another problem to be pointed out is that T-Ring is a flexible testbed and the cells in it can be configured to have different sizes. So Comparison of propagation for cells with different sizes is also a preliminary job.

2.1 Large-Scale Fading and RSSI

A terminal in T-Ring should experience a RSSI comparable with that in realistic networks. RSSI in most cases depends on path loss resulted from large-scale fading and transmission power of the base station. Large-scale fading is the result of signal attenuation due to propagation over long distance and diffraction around large objects in the propagation path. It directly affects wireless coverage. The commonly used propagation models are Cost231-Hata model for carrier frequency below 2 GHz [6] and Stanford University Interim (SUI) model for carrier frequency below 11 GHz [11]. Cost231-Hata model is represented by the following equations [6]:

$$\begin{aligned} PL[dB] = {} & (44.9 - 6.55\log_{10} h_{tx})\log_{10}\frac{d}{1000} + 45.5 \\ & +(35.46 - 1.1h_{rx})\log_{10} f_c - 13.82\log_{10} h_{tx} + 0.7h_{rx} + C \end{aligned} \tag{1}$$

Where:

PL - Path loss, dB

h_{tx} - Transmitter height, m

d - Distance between transmitter and receiver, m

h_{rx} - Receiver height, m

f_c - Carrier frequency, MHz

C - 0 dB for suburban area and 3 dB for urban area

Equation (1) shows that path loss depends on the logarithm of distance with fixed f_c, h_{tx} and h_{rx}. Assume that a terminal moves along a route, the path loss difference between the start point and the end point is obtained as:

$$PL_{start} - PL_{end} = \alpha\log_{10}(d_{start}/d_{end}) \tag{2}$$

Where d_{start} and d_{end} are the distances between both ends and the transmitter, α is a constant for simplicity. Let

$$d_{start}/d_{end} = \rho \tag{3}$$

Equation (2) and (3) show that pathloss depends on the relative distance ρ. So if the length of field test route is proportional to the cell size, the path loss variations along the route will be identical to the counterpart in the realistic cell. Furthermore, by appropriately configuring the transmission power of the base station, the RSSI in the T-Ring system along a field test route will be similar to that in the corresponding commercial networks.

2.2 Small-Scale Fading and RMS Delay Spread

Small-scale fading is a characteristic describing the rapid fluctuations of received power level due to small sub wavelength changes in receiver position. It can be regarded as the joint effect of multipath and the receiver movement. There are several characteristics that can be used to quantitatively analyze the small-scale

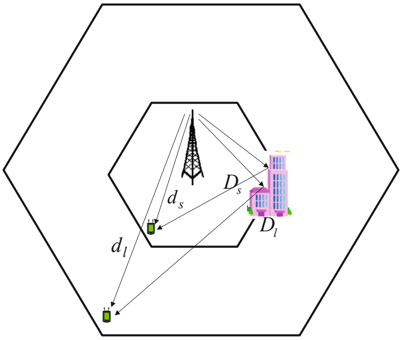

Fig. 2. Multipath for users in different-size cells

fading [10]. This paper will only focus on the multipath at present. For narrow-band wireless communication systems, multipath result in a flat fading. And for a wide-band system, multipath brings about frequency selective fading. So delay spread is a key feature for wireless channel. Here we use RMS delay spread for evaluating the similarity of multipath fading here. The RMS delay spread is defined as the standard deviation of the power delay profile [7]:

$$\tau_{RMS} = \left(\sum_{k=0}^{N} (\tau_k - \tau_e)^2 \frac{|P(\tau_k)|}{\sum_{i=0}^{N} |P(\tau_i)|} \right)^{1/2} \tag{4}$$

Where τ_e is average delay and $|P(\tau_i)|$ is the power of the ith path. Multipath results from the presence of reflection, diffraction and scattering. Since scattering is hard to model and the diffraction can be regard as reflection by virtual object, the following analysis of multipath will primarily focus on reflection. The simplification will not affect the analysis result of RMS delay spread. As shown in Fig. 2, two terminals locate in the cells with different distance from the base station. Assume there is a specific reflector with the distance D_s apart from the transmitter, the delay spread caused by the reflector is τ_1 for user at the short distance and τ_2 for users at the long distance respectively. The following relationships can be achieved

$$\tau_1 > \tau_2 \tag{5}$$

Equation (5) indicates that the multipath changes with the variation of the cell radius even for the same environment. The delay spread in a small cell will be larger than that in a larger cell. Though it is difficult to accurately control multipath effect, we still have some methods to handle some key parameters such as RMS delay spread. It is known that multipath is affected by the antenna tilt, antenna altitude and beam width. If we can make the statistical characteristic of RMS delay spread along the railway approximate that of a real-world field test, we achieve the goal of setting up a radio environment in T-Ring similar to that in a real network.

3 Quantitative Evaluation

After comparison of different-sized cells from aspects of RSSI and RMS delay spread, a quantitative evaluation expression is needed to describe the similarity of two environments. Because many parameters are conventionally investigated in statistical way, the similarity degree of two environments will also be evaluated statistically. For each radio characteristic, we analyze the measured data and calculate the probability density function (PDF) or the cumulative distribution function (CDF). Here we use CDF for evaluation. Then the similarity degree of the characteristic of two wireless environments is measured by

$$\lambda = 1 - \sqrt{\frac{\sum_i (x_i - x_i^{'})^2}{\sum_i {x_i}^2}} \tag{6}$$

Where x_i and $x_i^{'}$ are two series of sample data of CDF which range from 0 to 1. As a result, λ also ranges from 0 to 1, with 0 denoting that the characteristic of the two environments bear no resemblance and 1 denoting the reverse. If several characteristics are taken into account, a synthesis evaluation expression is needed. Provided the similarity degree of the two wireless environments on the i th characteristic is λ_i, the synthesized similarity degree λ_{syn} of characteristics is written as

$$\lambda_{syn} = \sum_{i=1}^{K} w_i \lambda_i \tag{7}$$

Where w_i is the weight factor of each similarity degree λ_i , and K is the number of characteristics to be involved in the evaluation. To obtain a reasonable synthesized similarity degree, the weight factor should be properly determined. From information theory aspect, the more difference a characteristic shows for different environments, the heavier weight it will be given. So the weight factor is defined as

$$w_i = \frac{1 - \lambda_i}{\sum_{k=1}^{K} (1 - \lambda_k)} \tag{8}$$

Where λ_i is an calculated similarity degree of i th parameter, and K is the number of characteristics that are involved in the evaluation. For an extreme example, a characteristic with a similarity degree 1 all the time for various wireless environments will contribute zero to the synthesized evaluation. Moreover, the weight factor of each parameter is normalized in equation (8).

4 Simulation and Example

To show the feasibility of the quantitative comparison method and the process of determining the wight factors w_i in the synthesized similarity degree as (8), we set up a simulation model as shown in Fig. 3. A set of reflectors from A to

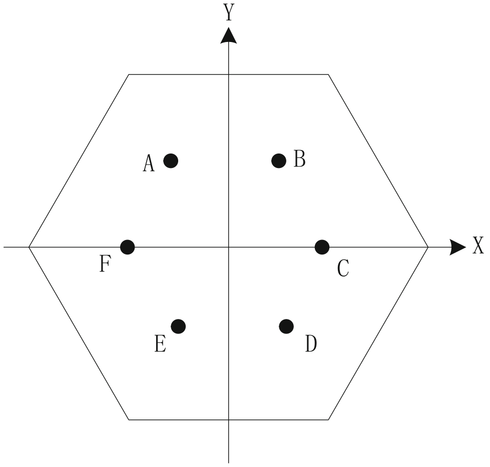

Fig. 3. Simulation Scenario

Table 1. Simulation Parameters

Parameter	**Value**
Height of TX antenna	30m
Height of RX antenna	1.5m
Frequency	1.9GHz
Radius of the cell	300m

F distribute in a single cell. The transmitter uses omnidirectional antennas and locates in the center of the cell. We ignore the shadowing effect to simplify the simulation. The simulation parameters are shown in TABLE 1. The coverage area is partitioned into hundreds of blocks. For each block, the power of the LOS path and the reflection path caused by the six reflectors are cumulated as RSSI. RMS delay spread can also be calculated with equation (4).

We first investigate the comparison of radio environments for cells with same sizes. We set up two simulation scenarios with the reflectors distributed in the cells uniformly or randomly. The RMS and RSSI are estimated and CDF of each characteristic is shown in Fig. 4. The result shows there is no much gap between CDFs of RSSI for the uniform distribution and random distribution, whereas the CDFs of RMS delay spread for the two kinds of distribution are quite different. With equation (6), we calculate the similarity degree and obtain $\lambda_{RSSI} = 0.9153$ and $\lambda_{RMS} = 0.6491$. The phenomenon indicates that RMS delay spread is more likely to display the difference of various environments. So RMS delay spread is expected to get a heavier weight than RSSI.

To determine the value of w_i for a specific cell size, we set up ten scenarios in which the reflectors are randomly distributed. Each scenario will be combined with another one for similarity degree evaluation. The similarity degree of RMS

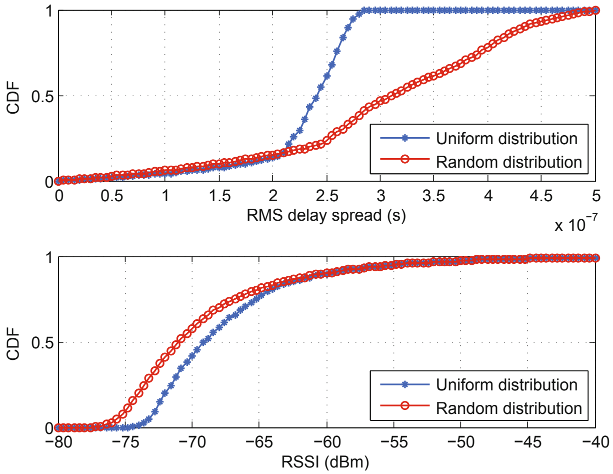

Fig. 4. CDFs of RMS delay spread and RSSI for uniform and random distributions

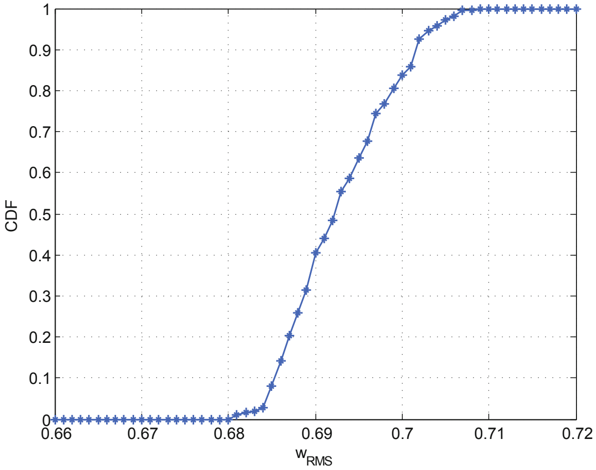

Fig. 5. CDF of w_{RMS} for various reflectors distribution in cells with same size

delay spread and RSSI of each possible pair is calculated as $\bar{\lambda}_{RSSI}$ and $\bar{\lambda}_{RMS}$. And corresponding w_i are acquired consequently with Equation (8). By analyzing the CDF of calculated w_{RMS} as shown in Fig. 5, w_{RMS} is obviously distributed within a narrow range of [0.680, 0.708]. That means $\bar{\lambda}_{RMS}$is estimated with small variance. So we define the estimated as

$$\bar{w}_i = \frac{1}{N} \sum_{n}^{N} w_{i,n} \tag{9}$$

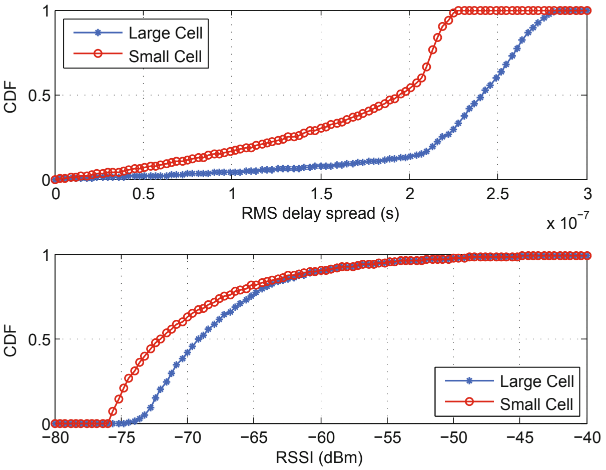

Fig. 6. CDFs of RMS delay spread and RSSI for different-sized cells

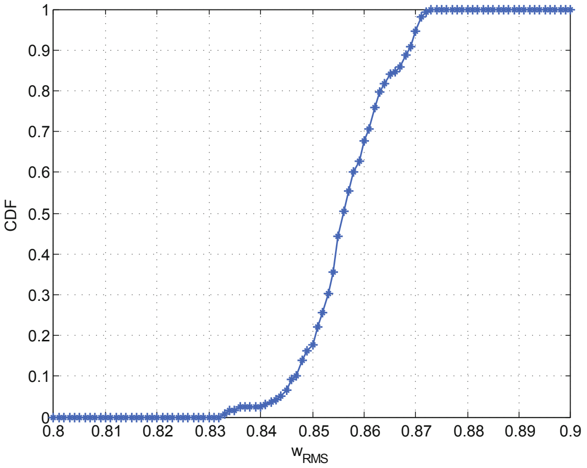

Fig. 7. CDF of w_{RMS} for different-sized cells

Where n is the index of w_i and N is the total number of the calculated w_i. Here simulation results shows $(\bar{w}_{RMS}, \bar{w}_{RSSI})$ is estimated as $(0.694, 0.306)$. Thus we obtain a comparison expression for cells with same size as

$$\lambda_{syn} = 0.694\lambda_1 + 0.306\lambda_2 \tag{10}$$

where λ_1 denotes the similarity degree of RMS delay spread and λ_2 denotes that of RSSI. The equation (10) will be used to compare the radio environments of cells with the same size.

With the same method, the comparison of cells with different size is also performed. Also we setup ten scenarios with six reflectors randomly distributed in a single cell. For each scenario, we consider two sub scenarios that the transmission power is changed so that larger coverage has a radius twice of the small one. Fig. 6 shows the CDFs of RMS and RSSI for different-sized cells, and Fig. 7 shows CDF of for different-sized cells. Consequently we estimate $\lambda_{RSSI} = 0.8778$ and $\lambda_{RMS} = 0.6879$. Thus $(\bar{w}_{RMS}, \bar{w}_{RSSI})$ is determined as $(0.85, 0.15)$. Thus we obtain a comparison expression for cells with different size as

$$\lambda_{syn} = 0.85\lambda_1 + 0.15\lambda_2 \tag{11}$$

where λ_1 denotes the similarity degree of RMS delay spread and λ_2 denotes that of RSSI. The equation (11) will be used to compare the radio environments of cells with the different size.

Through the simulation we find that the RMS delay spread differs widely for different scenarios, while RSSI are very close. That phenomenon results from the fact that the RSSI are dominated by the large-scale fading which is difficult to be demonstrated in the pure simulation scenario. But the multipath effect can be easily captured.

It should be pointed out that the above simulations and process only indicate the feasibility of the proposed method. The equation(10) and (11) only make sense for the scenario in this paper. A weight factor w_i for a special characteristic should be determined after data collection in real networks with the proposed method. So future work will concentrate on the calibration of this method and determine the comparison metric that will be used for T-Ring test system.

5 Conclusion

In this paper we introduce a new integrated wireless testbed, T-Ring. To satisfy some specific requirements, T-Ring should has the ability of being configured properly to approximate some specific radio environments. For that purpose, we present a quantitative comparison method of radio environments. We define a similarity degree to describe the relation of radio characteristics and a synthesized similarity degree to describe the relation of two radio environments. The method of determining the weight factor of each characteristic in the synthesized expression is also proposed. With the method, it is possible to describe how much a radio channel resembles another one. Simulations show that the quantitative comparison is feasible and indicate that parameters which are more likely to reveal the difference of various environments will get heavier weights. With the comparison method, we can first measure some wireless parameters in a cell and rebuild it on a computer-based simulation platform according to the evaluation metric. Then T-Ring will be adjusted to approximate the wireless environment of a real-world commercial network under the direction of the simulation platform. RSSI and RMS delay spread are currently presented to be involved in the quantitative comparison. Of course some other useful characteristics can be involved with the same method. That will be investigated in the future.

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