



QoE Evaluation of Scheduling Algorithms for NRT Services in LTE

Pablo AMEIGEIRAS¹, Juan J. RAMOS-MUNOZ¹, Jorge NAVARRO-ORTIZ¹,
Juan RAMIRO-MORENO², Juan M. LOPEZ-SOLER¹

¹ *Department of Signal Theory, Telematics and Communications, CITIC-UGR,
University of Granada, Granada, Spain*

Tel: +34 958242306, Fax: + 34 958240831, Email: pameigeiras@ugr.es

² *Optimi Corporation, Spain*

Abstract: An interesting approach for designing scheduling algorithms in OFDMA systems consists on incorporating a utility function that maps a certain resource or performance criterion into a value that measures the degree of user satisfaction. The current paper proposes a utility function that maps the user data rate into the quality of experience (QoE) perceived by the end user. The utility function is derived from a subjective survey of user experience quality for the Web browsing application for different service response times. The obtained utility function shows a similar slope to the natural logarithm function in the range of 100 kbps to 1Mbps, but it differs for higher data rates. Here, the utility function is applied in the evaluation of versions of the Generalized Proportional Fair (GPF) scheduler with different degrees of fairness in 3G LTE. It is shown that the application of the utility function allows the evaluation of the subjective user satisfaction provided by the GPF scheduler.

Keywords: Quality of Experience, subjective survey, OFDMA, 3G LTE.

1. Introduction

The 3GPP UTRAN Long Term Evolution (LTE) is a technological enhancement with ambitious design goals like providing a downlink average user data rate and spectral efficiency 3 to 4 times compared to Release 6 High Speed Downlink Packet Access (HSDPA) [1]. One of the key characteristics of LTE is the use of Orthogonal Frequency Division Multiple Access (OFDMA) as the user multiplexing technique in the downlink direction. The use of OFDMA allows to dynamically multiplex users in the frequency and the time domains. By using information about the instantaneous radio conditions experienced by the users in the cell, the base station can serve users on a per Transmission Time Interval (TTI) basis on those frequency sub-bands with favourable channel quality.

There exists a wide set of algorithms in the literature that deal with the dynamic assignment of frequency and time resources in downlink of OFDMA systems. Some of these works [2]-[4] have focused on algorithms that aim at maximizing the aggregate of a utility function over all the users in the cell. The utility function maps a given performance criterion (typically the average data rate for Non Real Time -NRT- services) into a value that measures the degree of user satisfaction. The use of a utility function in the maximization of the aggregate utility allows determining the degree of fairness among the users in the cell. For example, it has been proved that, by using the natural logarithm utility function (as initially proposed by Kelly [5]), the allocation of average user data rates is proportionally fair [4].

In [6], Song takes a further step by proposing a theoretical framework to maximize the aggregate of a utility function based on the subjective quality experienced by the end user.

Song makes use of a utility function obtained through sophisticated subjective surveys where users are asked to judge the application performance under different average data rate conditions. Moreover, Song concludes that, under certain conditions, a gradient scheduler that takes into account the instantaneous Channel Quality Information (CQI) and the gradient of the utility function leads to maximizing the aggregate of the users' utilities.

The work in [6] represents an interesting approach for designing scheduling algorithms for OFDMA systems. The utility function employed in that work is based on the subjective quality survey of data applications carried out in [7]. Unfortunately, that survey only evaluated the quality of experience for user data rates up to 150 kbps. Although the user data rates provided by OFDMA systems strongly depend on several factors such as the available bandwidth, the indoor/outdoor scenario, the transmitter and receiver antennae configuration, etc., the results in [8]- [9] show that OFDMA systems render user data rates significantly higher than 150 kbps. Hence, the design and evaluation of scheduling algorithms based on the utility of the quality of experience in OFDMA systems require utility functions that extend the range of data rates considered in [7].

For this reason, this work carries out a new subjective survey of user experience for one of the most representative NRT services: Web browsing. Additionally, a utility function of user quality experience is derived from the survey results. Finally, the derived utility function is applied to the evaluation of the Generalized Proportional Fair (GPF) scheduling algorithm [8] in 3G LTE.

The rest of this paper is organized as follows. Section 2 describes the subjective survey of user experience for Web browsing. Section 3 derives the utility function of user experience quality based on the survey results. Section 4 describes the GPF scheduling algorithm and section 5 details the simulation system model. Section 6 presents the user quality experience results of the GPF evaluation and section 7 draws the main conclusions.

2. Subjective Survey of User Experience for Web Browsing

Although Web browsing cannot be considered representative for all NRT applications, it is expected to be one of the most relevant applications in future wireless networks such as 3G LTE. Therefore, in this work we concentrate on Web browsing for the survey.

As Web browsing is considered to belong to the Interactive Quality of Service (QoS) class, one of the key QoS metrics that determine its performance is the service response time. Hence, we select the service response time as the QoS network performance metric to be manipulated during the experiment.

2.1 Experimental Testbed

The testbed has been designed to provide an experimental condition similar to what a human user with a computer would experience when downloading a Web page from a remote Hypertext Transfer Protocol (HTTP) server through a wireless link. The service response time (i.e. the elapsed period since the instant of the request by the user until the Web page has been completely downloaded) is artificially controlled by a customized HTTP server. During the experiment, every participant uses a Mozilla Firefox Web browser [10] to download a total of 14 Web pages, every page with an ever increasing service response time (ranging from 600 milliseconds to approximately 60 seconds).

The HTTP server is a simple iterative server written in C that implements the HTTP/1.1 GET and HEAD methods using non-persistent connections. The requested objects, located at the local filesystem, are served as simple HTTP/1.1 responses through a Berkeley Software Distribution (BSD) socket [11]. The HTTP server controls the download time by sleeping its execution with the `usleep` linux function. In order to avoid other possible sources of delay, the HTTP server is executed locally in the same client machine.

2.2 The Web Page Contents, Survey Participants and Quality Ratings

Results presented in [12] support the anecdotal evidence that not only the service response time affect the user perception of Internet sites, but also the media contained in the Web document. However, the objective of the current experiment is to assess only the effect of the service response time and eliminate the effect of the media contents. Due to this reason, Web pages are constructed explicitly for the experiment. The criterion selected for the page design is to maintain the same structure between the different Web pages. The Web documents consist on photos from a monument, and the pictures differed from one Web document to another. By using the same format, the effect of the media contents is expected to be homogeneous across all pages. A set of 14 Web documents were created, one for every service response time.

A total of fifty two subjects were recruited as volunteers for participation. The subjects were undergraduate students of Telecommunications Engineering. They all have WIFI Internet access at the campus, and they are also very familiar with Web browsing and other Internet applications.

As in [7], the participants are requested to rank the quality they perceive according to the numerical rating indicated in Table 1. The quality rating scale is similar to the Mean Opinion Score (MOS) employed in traditional telephone voice quality tests. The participants may use fractional ratings with up to one decimal if their perceived quality is between that indicated by two integer scores. The participants are not permitted to use ratings below 1 or above 5.

Table 1: User Experience Quality Rating Scale

Score	User Experienced Quality
5	Excellent, I really like the way it works
4	Good, but I can see a few possible improvements
3	Acceptable
2	Somewhat annoying, but I can live with it
1	Terrible, I will not use it unless it is absolutely necessary

Before every participant starts the experiment, an example Web page is downloaded by an instructor with the objective that the subject becomes familiar with the experiment setup, and the graphical structure of the Web page. Moreover, before starting the experiment, every participant is requested not to evaluate the download quality comparing to previous downloads of the experiment, but rather to their daily use of the Internet access (e.g. at the university through the WIFI).

2.3 Survey Results

Figure 1 depicts the mean and the standard deviation of the fifty two opinion scores obtained for every tested service response time. As the service response time increases, the mean opinion score presents a negative-exponential like behaviour. The MOS decay is more evident for service response times between 0 and 10 seconds, whereas for service response times longer than 10 seconds the decrease is less pronounced. It is also relevant to note that, for service response times longer than 10 seconds, the MOS is already below two (i.e. the mean perceived quality is rated between “terrible” and “somewhat annoying”).

The results also show that, for service response times from four to twelve seconds, the standard deviation increases due to the increased difference in the participant opinion scores.

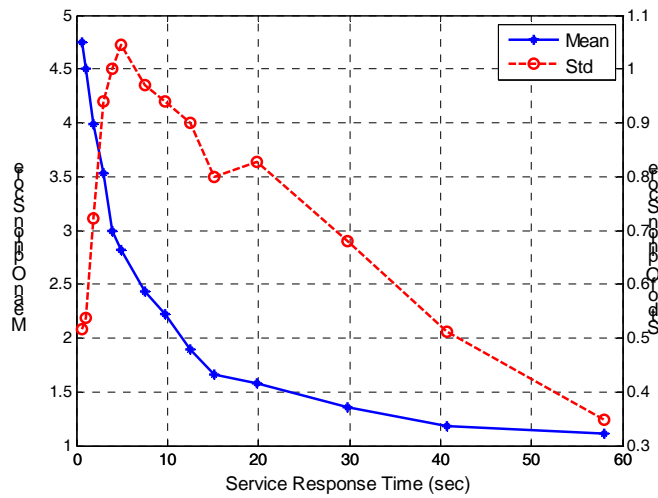


Figure 1: Mean and standard deviation of opinion scores of subjective user experience for Web browsing

3. Derivation of a Utility Function of User Experience Quality for Web Browsing Application

As described in [6], utility functions allow mapping the use of certain resources (bandwidth, time-slots, etc.) or performance criteria (data rate, delay, etc.) into the corresponding utility or price values. The incorporation of utility functions into the decisions of resource allocation strategies allows optimizing the overall utility provided by the network. By selecting the subjective user experience as the utility criterion, the network can enhance the user quality of experience.

The experimental results presented in previous section provide a method to assess the user experience quality as a function of the service response time for Web browsing. However, the service response time is a metric that cannot be incorporated in the decisions of resource allocation strategies because it is not available until the document has been completely downloaded. For this reason, the majority of the authors in the literature typically employ the user data rate as the performance criterion to be mapped into utility.

Unfortunately, the relation between the user data rate provided by a wireless link and the service response time of Web browsing depends on several factors such as the Web page size, the round trip time, the effects of protocols like Transport Control Protocol (TCP) and HTTP, etc. In order to simplify the problem, here it will simply be assumed that the service response time is exclusively determined by the data rate of the wireless link and the Web page size, so the remaining factors can be disregarded. Hence, the user data rate will simply be computed dividing the Web page size by the service response time. Moreover, a Web page size of 130KB will be assumed (i.e. the average Internet Web page size according to [13]).

Figure 2 plots the mean opinion score as a function of the user data rate. Additionally, Figure 2 also depicts the corresponding curve fitting with the Lorentzian function U provided in equation (1):

$$U(\bar{r}) = 5 - \frac{578}{1 + \left(\frac{\bar{r} + 541.1}{45.98}\right)^2} \quad (1)$$

where \bar{r} denotes the user data rate in kbps, and U is the fitting function. The function U can be used as a utility function that directly maps the user data rate into MOS.

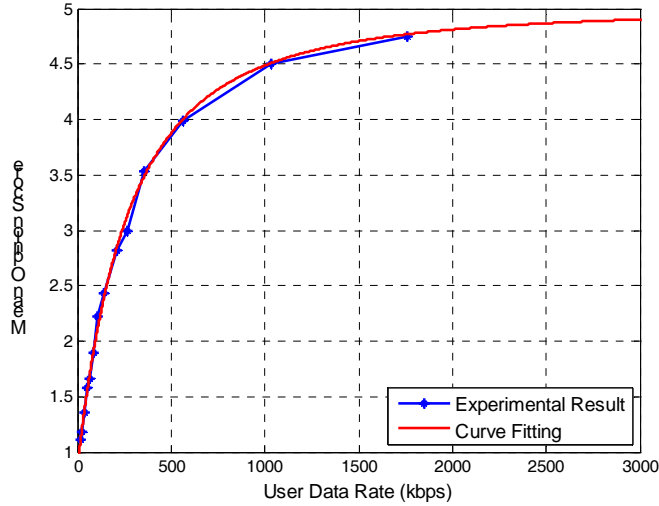


Figure 2: Experimental Result and Curve Fitting of Mean Opinion Score as a Function of User Data Rate

The results presented in Figure 2 indicate that the MOS approaches one as the user data rates tends to zero, and vice versa, the MOS tends to five for very high user data rates. Note that there exists no minimum user data rate (e.g. 128, 256, 384, etc) that provides no user satisfaction at all (i.e. MOS equals one). Additionally, no perceptual benefit is achieved by means of increasing the user data rate beyond 1-1.5 Mbps. The main increase of the MOS curve is produced for user data rates up to 500 kbps.

A direct comparison of the utility function of equation (1) to the natural logarithm utility function (used by Kelly in [5]) is difficult because both functions do not share the same utility dynamic range. For example, the maximum utility of function U reaches five, whereas the utility of the natural logarithm is not upper limited. However, for designing resource allocation strategies, the slope of the utility function is the most relevant metric. For this reason, Figure 3 plots the derivatives of both utility functions. The results of Figure 3 show that the slopes of both utility functions are quite similar in the range of data rates from 100 to 1000 kbps. However, for data rates higher than 1Mbps, the derivative of the utility function of equation (1) is significantly lower than the derivative of the natural logarithm due to the saturation of the MOS curve (see Figure 2). Additionally, in the low user data rate region, the slope of the utility function of equation (1) is limited to approximately 10^{-2} .

4. Packet Scheduling Algorithm for 3G LTE

As commented in section 1, there exists a wide set of publications that deal with the dynamic assignment of frequency and time resources in OFDMA systems. Due to its simplicity, and its ease to control the degree of fairness provision, the GPF [8] has been selected as the scheduling algorithm for evaluation. The GPF algorithm serves in every resource block (frequency sub-band) and TTI the user with highest priority:

$$P_k[n,s] = \frac{[r_k[n,s]]^\alpha}{[\bar{r}_k[n]]^\beta} \quad (2)$$

where $P_k[n,s]$ denotes the priority of user k on the resource block s and on TTI n , $r_k[n,s]$ is the instantaneously supported data rate of user k on the resource block s and on TTI n , and $\bar{r}_k[n]$ is the low-pass filtered data rate that the user k has received until TTI n . $\alpha \in [0,\infty)$ and $\beta \in [0,\infty)$ are two weighting factors that allow controlling the fairness.

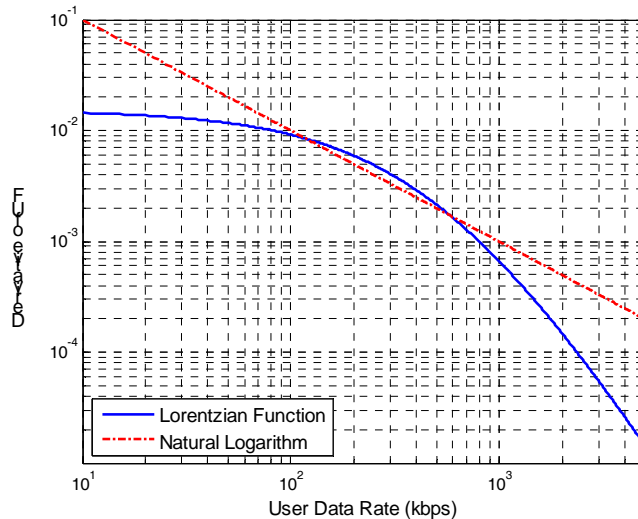


Figure 3: Experimental Result and Curve Fitting of Mean Opinion Score as a Function of User DataRate

Increasing β and/or decreasing α improve the provision of user data rate fairness at the expense of cell throughput, and vice versa. In the current work, four algorithm parameter settings are selected for evaluation: *i*) $\alpha = \beta = 1$, i.e. the conventional Multi-carrier Proportional Fair algorithm, *ii*) $\alpha = 2, \beta = 1$, an unfair version of the Multi-carrier PF algorithm, *iii*) $\alpha = 1, \beta = 2$, a fair version of the Multi-carrier PF algorithm, and *iv*) $\alpha = 1, \beta = 0$, i.e. the Max Rate scheduler.

5. System model

In order to evaluate the user experience quality provided by the GPF algorithm in 3G LTE, a quasi-dynamic network simulator is used. Its main parameters and assumptions (see [9]) are presented in Table 2.

Table 2: Simulation Parameters and Model Assumptions

Parameter	Setting	Parameter	Setting
Carrier frequency	2 GHz	CQI signalling delay	4 ms
System bandwidth	10 MHz	Target BLER for outer loop link adaptation	20%
Resource block bandwidth	375 kHz	HARQ model	Ideal Chase Combining
Sub-carriers per RB	25	Number of stop and wait processes	6
Sub-frame duration	0.5 ms	User data rate low-pass filter length	300 ms
Inter-site distance	2 km	Mean offered cell load	11Mbps
Std of shadow fading	8dB	Max number of users in cell	40
Power delay profile	ITU Typical urban 20 paths	Admission control blocking criterion	New user is blocked when there are max number of users in the cell
Antenna receiver scheme	2 – rx (Maximal ratio combining)	Dropping criterion	User is dropped if it does not reach a throughput of at least 50kbps for a period of 4 sec
UE speed for fast fading process	3 km/h		
Error in CQI estimation	Gaussian (zero mean, 1 dB std)		

Users are only simulated in the central cell of a hexagonal grid of thirteen cells. Users do not vary their geographical location with time, and therefore, their deterministic path loss and shadow fading remains invariable during the lifetime of the user. However, users experience a fast fading process that is updated in each TTI based on the ITU Typical Urban (TU) power delay profile. The link-to-system level mapping is based on the

Exponential Effective SIR Metric (EESM) model [14]. Users are created according to a Poisson process whose mean offered cell load is controlled by a simulation parameter. A simplified Web browsing model consisting in a 2Mbit payload is included. Simple admission control and user dropping algorithms are included in the modelling (see Table 2).

6. Simulation Results

The present section evaluates the user experience quality provided by the GPF algorithm in 3G LTE. As described in section 4, four versions of the GPF algorithm are assessed.

Figure 4 illustrates the CDF of the data rate of non-blocked users for an offered cell load of 11Mbps. As expected, the results show that the unfair versions of the GPF algorithm exploit the potential of users with favourable channel quality conditions at the expenses of starving those with poor channel quality conditions. On the other hand, the fair version of the GPF algorithm (i.e. $\alpha = 1, \beta = 2$) achieve a higher user data rate at the tail of the CDF (i.e. coverage improvement).

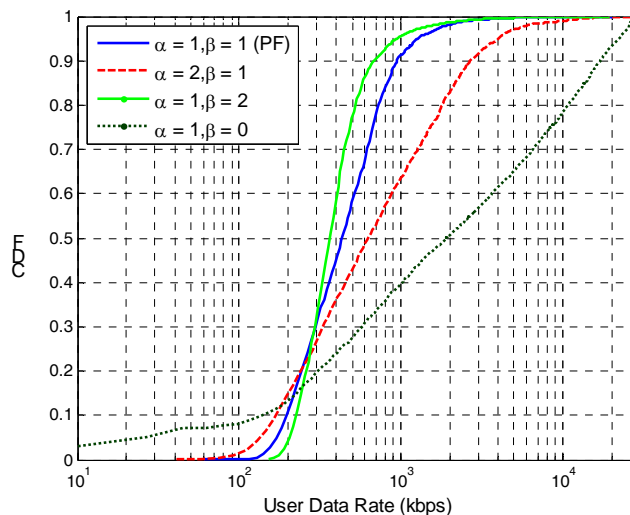


Figure 4: CDF of Data Rate of Non-Blocked Users for Four Different GPF Parameter Settings

The quality experienced during Web browsing can be evaluated by applying the Lorentzian utility function (see equation (1)) to the data rates of the users in the cell. Figure 5 depicts the CDF of the experienced quality. Considering, for example, the Multi-carrier PF algorithm, it can be seen that approximately 40 % of users experience a performance from “good” to “excellent” (see Table 1), approximately other 40 % of users experience a performance from “acceptable” to “good”, while the remaining 20% experience a performance from “annoying” to “acceptable”.

7. Conclusions and Further Work

In the current work, a subjective survey of user experience has been carried out where participants have rated the performance of the Web browsing application for different service response times. From the experimental data, the mean opinion score (MOS) has been computed as a function of the service response time.

Based on the survey results, a utility function that maps the user data rate into MOS has been derived for a Web page of 130 KB. Similarly, other page sizes could be selected depending on the sizes of the web contents to be downloaded. The application of the derived utility function allows mapping the user data rates into the user experience qualities for the Web browsing service. Therefore, it enables to assess the performance of wireless networks and their algorithms from a subjective user satisfaction perspective. As a use case,

the present work has compared the performance of four versions of the GPF algorithm from a Quality of Experience viewpoint in 3G LTE.

Additionally, the obtained utility function can be incorporated into resource allocation strategies. This incorporation can be done in OFDMA systems following the strategy presented in [6] that has the objective of maximizing aggregate utility over all users in the system. By selecting the subjective user experience as the utility criterion, this approach would aim at optimizing the overall quality experienced provided by the system to the end users. The incorporation of the obtained utility function in the framework presented in [6] and its evaluation is left for further work.

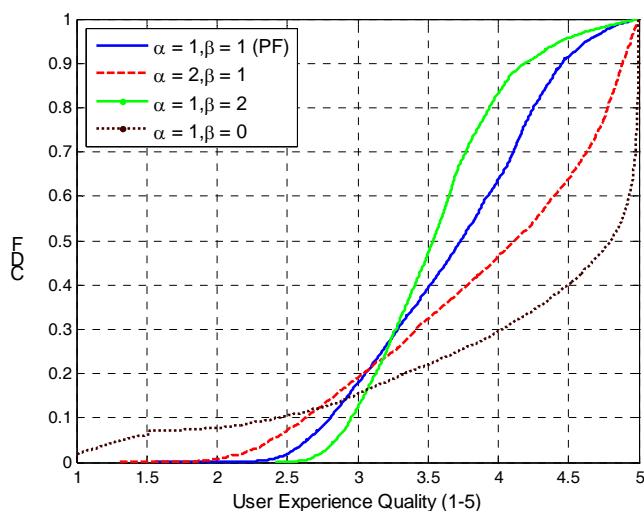


Figure 5: CDF of Experienced Quality of Non-Blocked Users for Four Different GPF Parameter Settings

References

- [1] 3GPP, "Long Term Evolution of the 3GPP radio technology". <http://www.3gpp.org/Highlights/LTE/LTE.htm>.
- [2] R. Santos et al, "QoS Based Radio Resource Allocation and Scheduling with Different User Data Rate Requirements for OFDMA Systems" *Personal, Indoor and Mobile Radio Communications, 2007*, pp.1-5, 3-7 Sept. 2007.
- [3] T. Nguyen and Y. Han, "A Proportional Fairness Algorithm with QoS Provision in Downlink OFDMA Systems" *Communications Letters, IEEE, 2007*, vol.10, no.11, pp.760-762, Nov. 2006.
- [4] H. Kim and Y. Han, "A Proportional Fair Scheduling for Multicarrier Transmission Systems" *Communications Letters, IEEE*, vol.9, no.3, pp. 210-212, March 2005.
- [5] F. Kelly, "Charging and Rate Control for Elastic Traffic (corrected version)" *European Transactions on Telecommunications*, vol.8, no.1, pp. 33-37, January 1997.
- [6] G. Song and Y. Li, "Cross-Layer Optimization for OFDM Wireless Network – Part I and Part II" *Wireless Communications, IEEE Transactions on*, vol.4, no.2, pp.614-634, March 2005.
- [7] Z. Jiang et al, "A Subjective Survey of User Experience for Data Applications for Future Cellular Networks" *Applications and the Internet, 2001. Proceedings. 2001 Symposium on*, pp.167-175, 2001.
- [8] C. Wengerter et al, "Fairness and Throughput Analysis for Generalized Proportional Fair Frequency Scheduling in OFDMA" *Vehicular Technology Conference, 2005. VTC 2005-Spring*, vol.3, pp. 1903-1907, 30 May-1 June 2005.
- [9] A. Pokhariyal et al, "HARQ Aware Frequency Domain Packet Scheduler with Different Degrees of Fairness for the UTRAN Long Term Evolution" *Vehicular Technology Conference, 2007. VTC 2007-Spring*, pp. 2761-2765, 22-25 April 2007.
- [10] Mozilla firefox Web site, www.mozilla.org
- [11] W. Stevens, "Unix Network Programming". Prentice-Hall. 1990.
- [12] J. Jacko et al, "The Effect of Network Delay and Media on User Perceptions of Web Resources", *Behaviour and Information Technology*, vol.19, no.6, pp.427-439, November 2000.
- [13] A. King, "The Average Web Page", www.optimizationweek.com/reviews/average-Web-page, October, 2006.
- [14] Y. Blankenship et al, "Link Error Prediction Methods for Multicarrier Systems" *Vehicular Technology Conference, 2004. VTC 2004-Fall*, vol.6, pp. 4175-4179, 26-29 Sept. 2004.