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TESTING OF FIXED BROADBAND WIRELESS SYSTEMS AT 5.8 GHZ

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ABSTRACT

The advent of 802.16-2004 standard for Wireless Metro Area Network (MAN) has created interest amongst telecom service providers. Equipment manufacturers are already marketing point-to-point and point-to-multipoint broadband wireless systems in the 5.8 GHz unlicensed band for fixed applications.

Before deploying on a large scale, a precise estimate of capacity and coverage of these systems is needed. This report gives an insight on expected throughput and performance for equipment based on 802.16-2004, using TDD, OFDM, 256 FFT, and many of the WiMAX choices made for use at 5.8 GHz.

Tests are setup in different environments, in the lab and outdoors: we first report on a study in a controlled lab environment, where radio multipaths and fades are generated by a channel emulator, simulating Stanford University Interim (SUI) channel models; then the same radio system is tested for throughput in a suburban area in Denver. The two experiments are compared.

INTRODUCTION

Our study is motivated by the need to accurately predict performance of a radio link for fixed broadband access. This study focuses on measuring actual data throughput data rates in various test setups; it does not however show detailed radio signal levels, noise or interference levels and is therefore somewhat incomplete in that respect, but it offers good data points of what may be expected in the rollout of fixed broadband radio links.

Radio systems under test are TDD, OFDM, based on 802.16-2004 WirelessHUMAN physical layer ([1] section 8.5), using 256 FFT in a 20MHz channel at 5.8 GHz. We study one sector only (90 degree azimuthal beam width); a spectrum survey shows a clean environment (with average receiver interference levels below -96dBm both in lab and in the field) and we do not take into account other-cell or other-channel interference issues.

A major portion of this paper deals with Stanford University Interim (SUI) channel models for propagation, these SUI models were presented to the IEEE 802.16 study group [2] and are often used in conjunction with WiMAX radios, especially at 2.3GHz to 2.5.5GHz. We should however emphasize that these models are based on cellular PCS base stations at 1.9GHz (as noted in [2] and [3]), and as a result these models might not be applicable at 5.8GHz.

Nevertheless, [2] reports that some SUI models show close fit to the Cost-231 Walfish Ikegami model, and our own tests [4] show that near line-of-sight data links at 5.8GHz also show a good fit to that model. This justifies our interest for SUI models at 5.8GHz.

CONTROLLED ENVIRONMENT TESTS

1) *Test Setup*

The radio system under test comprises one base station (BS) and several subscriber stations (SS's). Tests were conducted to measure the throughput of radio links in different modulations. Devices were tested in a part-cabled environment and part-unbounded media as shown below. The cabled environment undergoes different fading channels programmed in a fading emulator. The air interface is a short direct line of sight between BS and SS's of approximately 10 feet.

The Fading emulator allows us to emulate two separate channels (forward and reverse links), each comprised of several multipaths, each of which is independently faded and delayed. Fade statistics for the direct path are either Rayleigh or Ricean, delayed paths are attenuated and Rayleigh faded as specified in [2] and summarized in Table 1.

As in many wireless LAN devices, our radio devices are TDD and have duplex ports: transmit and received signals are cabled to the same antenna. In this test, because of the unidirectional nature of the fade emulator, our transmit and receive paths are separated by circulators and faded by two independent channels. Additional attenuation (pad) is added where necessary. Finally a traffic generator is connected (via 100bT Ethernet) to the BS and laptops are connected to SS's for data collection. Figure 1 shows the detailed setup.

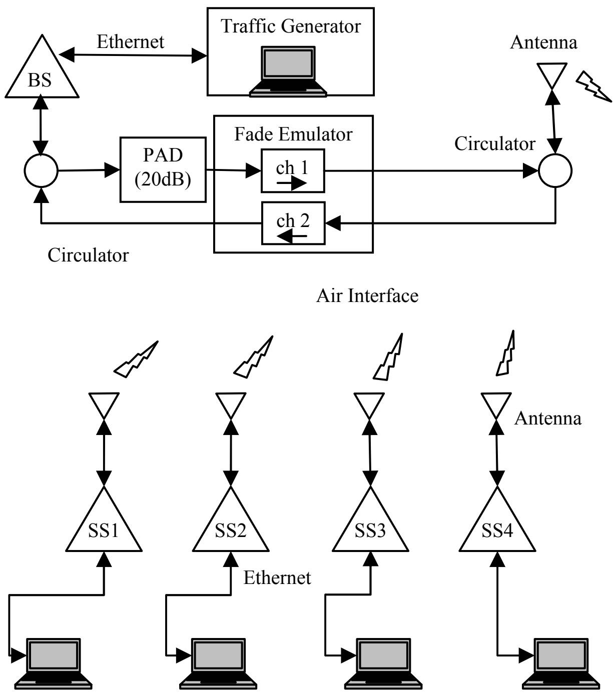

Fig. 1. Test Setup.

2) Channel Models

Different channel models are emulated using the modified Stanford University Interim (SUI) models. To simplify we focus on 3 of the usual 6 SUI models: SUI-1, 3, and 5, described in table 1 below. SUI-4 & 6 have high Doppler spread and are less relevant to fixed access, SUI-2 shows similar results to SUI-1 for our purpose. We therefore have a model for different terrain types A, B, and C, as described below (for more details, refer to [2], [3]).

Table 1: Fading Channel Models

Model	SUI-1	SUI-3	SUI-5
Terrain Type	A: Flat, light tree density	B: Hilly, light tree density or Flat, moderate to heavy tree density	C: Hilly, moderate to heavy tree Density
Doppler	Low	Low	Low
Delay spread	Low	Low	High
Ricean K of direct path	4 (High)	1 (Low)	0 (Rayleigh)
Multi-path (delay & atten.)	3 paths, 1: direct 2: 0.4µs, -21dB 3: 0.9µs, -30dB	3 paths, 1: direct 2: 0.4µs, -11dB 3: 0.9µs, -22dB	3 paths, 1: direct 2: 14µs, -11dB 3: 20µs, -22dB

Throughput results are measured for these different SUI models and different modulations and coding: in particular 802.16-2004 and WiMAX conformance standards consider BPSK, QPSK, 16QAM and 64QAM, with forward error correction coding (convolutional coding) with a coding rate of 1/2, 2/3, or 3/4. Again to simplify we only consider four such modulations as indicated in Table 2.

Table 2: Modulations and Coding Tested

Modulation	Coding Rate	Expected Receiver SNR (dB) from [1]	Tests reported
BPSK	1/2	6.4	X
QPSK	1/2	9.4	
QPSK	3/4	11.2	X
16QAM	1/2	16.4	
16QAM	3/4	18.2	X
64QAM	2/3	22.7	X
64QAM	3/4	24.4	

3) Time-Varying Throughput

We first examine instantaneous variations of throughput in time. Our channel models are increasingly faded from SUI 1, to 3, to 5. Throughput remains steady with some short degradation during fades. In BPSK, the SUI model has barely any impact on throughput, at higher modulations, degradation is noticeable. Figures 2 & 3 show actual TCP payload (in Mbps) over several minutes for one SS in use in different channel models and for different modulations.

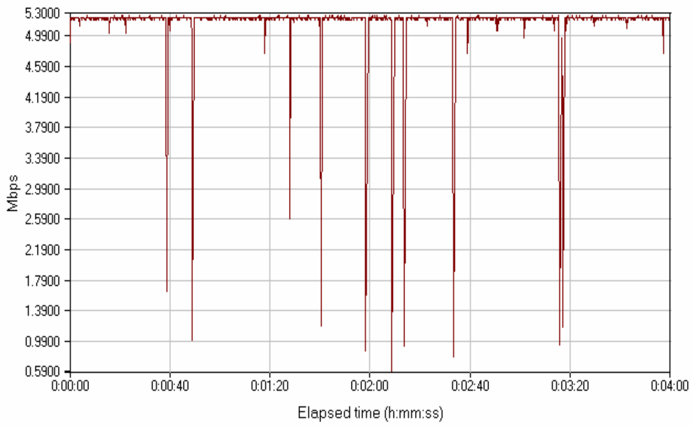

Fig. 2. Throughput vs. time for 1 SS, BPSK modulation in SUI-1 channel model.

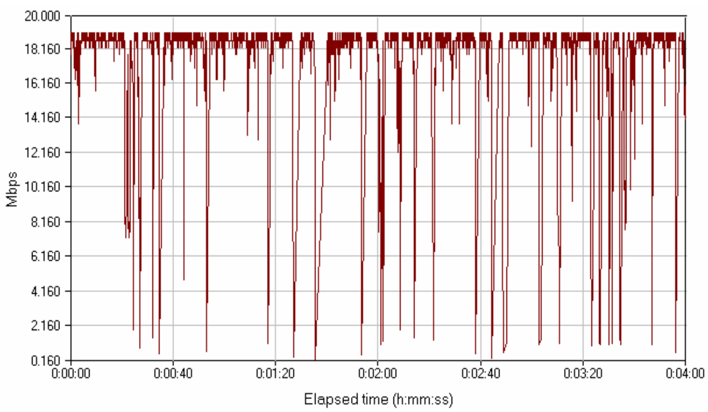

Fig. 3. Throughput vs. time for 1 SS, 64 QAM modulation in SUI-5 channel model.

When several simultaneous users are measured the overall throughput remains similar, with a lower average throughput for each customer. Our tests simulate constant simultaneous demand but increasing fades cause more rate variations between users. Figures 4 and 5 show results for 4 SS's in use. All SS's go through the same two fading channels (forward and reverse link) but in different time slots.

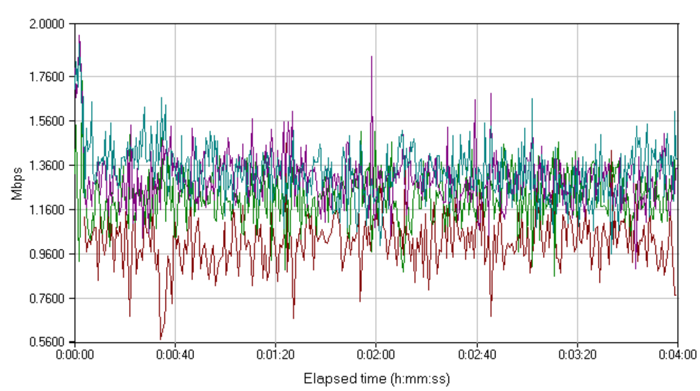

Fig. 4. Throughput vs. time for 4 SS's, BPSK, SUI-1.

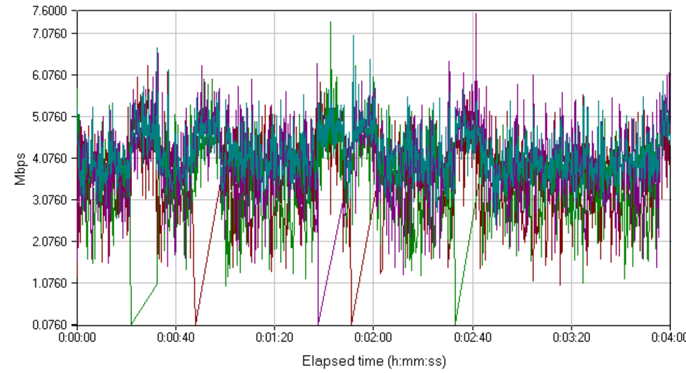

Fig. 5. Throughput vs. time for 4 SS's, 64 QAM, SUI-5.

Note that in Figure 5, SUI-5 fades are such that one SS may lose the link for a couple of seconds, in which case the other three SS's benefit from the added capacity.

Overall average throughputs are summarized below.

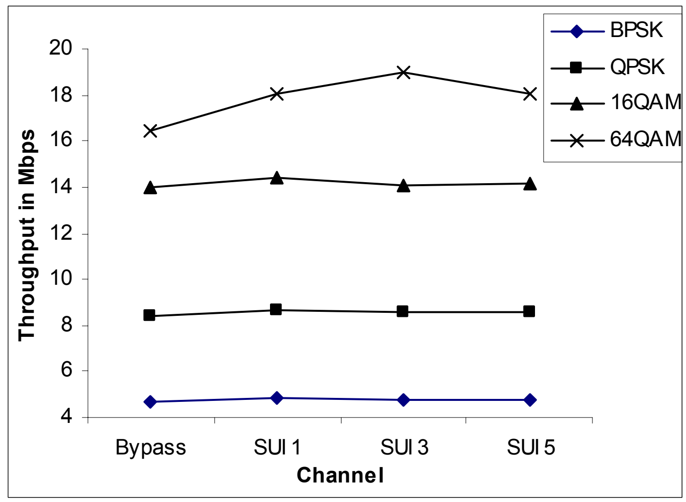

Fig. 6. Average throughput in Mbps for various channel models at different radio signal modulations.

(In the case of 64QAM modulation data throughput may have suffered from distortion or self-interference due to our cabled test setup, and measured throughput may not measure true capability of the system under test).

4) Throughput Distribution

Average throughput comparison shows no significant degradation as modulation increases. Table 2 and Figure 6 show statistics for actual measured bit rate in four channel models: one flat channel, going through a non-attenuating fade emulator, and three SUI models. In each channel, throughput statistics are measured for different modulations.

Table 3: Lab Throughput Statistics
Mean (m) and Standard Deviation (σ) in Mbps

Model	Static Channel	SUI-1	SUI-3	SUI-5
BPSK	m=4.698 σ=1.220	m=4.812 σ=0.664	m=4.782 σ=0.791	m=4.775 σ=0.805
QPSK	m=8.416 σ=1.112	m=8.627 σ=1.664	m=8.599 σ=1.665	m=8.605 σ=1.659
16QAM	m=14.018 σ=2.718	m=14.420 σ=1.907	m=14.058 σ=3.085	m=14.133 σ=3.093
64QAM	m=16.428 σ=4.623	m=18.032 σ=3.598	m=18.960 σ=3.767	m=18.090 σ=3.826

Probability analysis of the throughput levels show the following cumulative distribution functions.

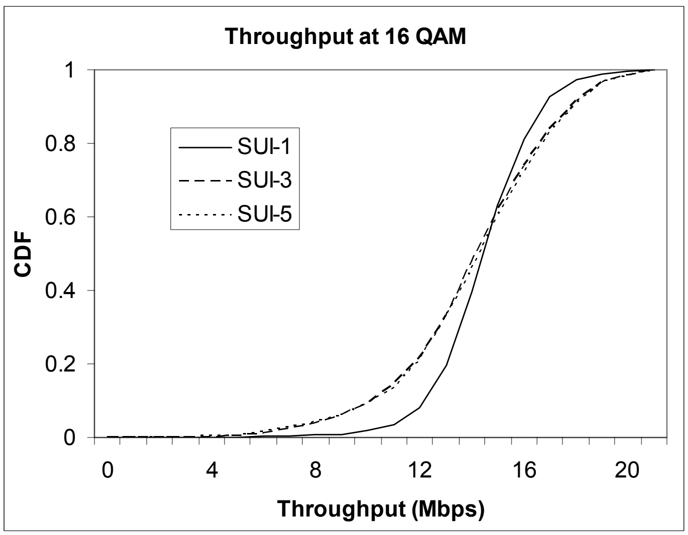

Fig. 7. Cumulative distribution of throughput in 16 QAM modulation, for SUI-1-3-5.

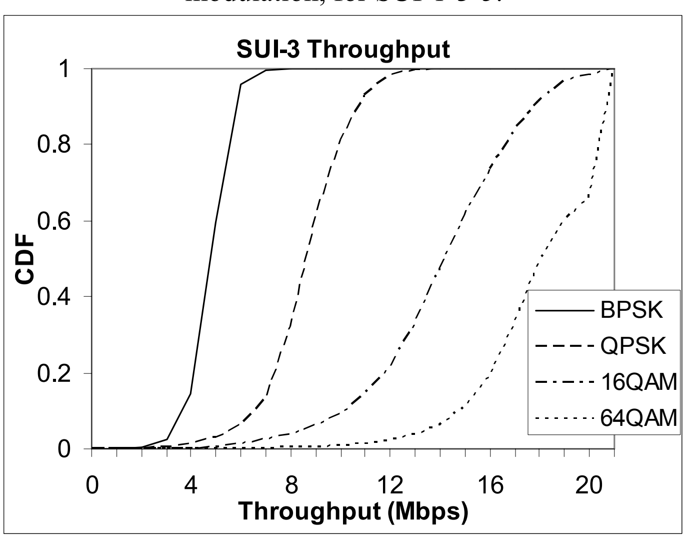

Fig. 8. Cumulative distribution of throughput for SUI-3.

Although different SUI models present significant differences in fading, it seems that 802.16-2004 radio systems are well equipped to deal with these fades efficiently and distribution functions look similar for a given modulation.

5) Comments on point-to-point

Point-to-multipoint throughputs do not exceed 20 Mbps, partly due to the fact that the BS must include some inefficiencies as it schedules different SS's on different time slots. It may be interesting to test what maximum throughput can be expected in a more efficient point to point system. As these radio links may be setup with high gain antennas and in good line of sight. Throughput is improved as reported in Table 4.

Table 4: Throughput Statistics for point-to-point
Mean (m) and Standard Deviation (σ) in Mbps

Model	Static Channel	SUI-1
BPSK	m=5.979 σ=0.026	m=5.222 σ=0.026
QPSK	m=11.809 σ=0.073	m=10.077 σ=0.074
16QAM	m=22.999 σ=0.458	m=18.482 σ=0.567
64QAM	m=40.102 σ=3.370	m=35.602 σ=3.890

OUTDOORS TESTS

1) Test Setup

After the lab study we take the same equipment and conduct true field testing in a suburban area in Denver. Tests setups are similar to those of Figure 1, but the circulators, padding and fade emulator are removed. The BS is placed on top of a 13-floor-high building, and the SS's are placed 6 feet off the ground, on small pedestals on vehicle roofs. The setup is also different in one major aspect: a modulation on demand is allowed where each SS is allowed to choose a specific modulation according to its SNR. Unlike the lab test, the field test has the BS communicate with SS's at different modulations.

2) *Time-Varying Throughput*

We first test throughput with one single SS at various locations within the sector. All locations are in somewhat obstructed line of sight, some only by minor foliage, some completely shadowed by buildings.

Table 5: Sector Throughput Statistics
Mean (m) and Standard Deviation (σ) in Mbps

Location 1	Location 2	Location 3	Location 4	Location 5
m=11.362 σ=1.877	m=8.042 σ=2.896	m=14.773 σ=0.328	m=14.746 σ=0.587	m=8.212 σ=3.442

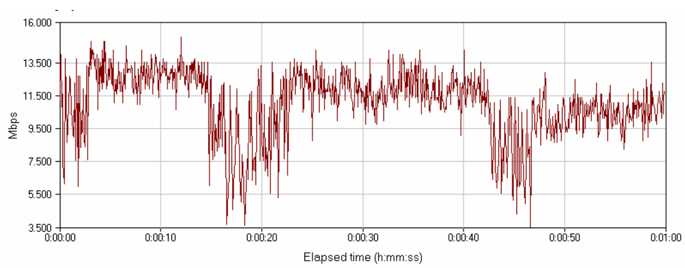

Fig. 9. Time varying throughput in Mbps for one unit during field testing.

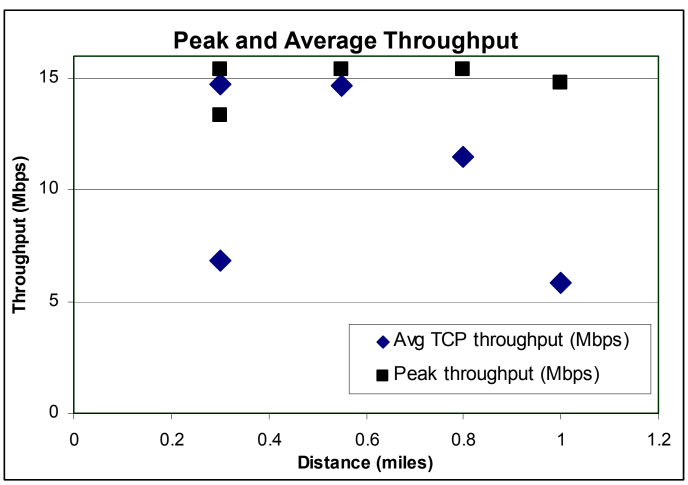

Fig. 10. Average and peak throughput in Mbps for various locations within a sector in actual field testing.

Next we test throughput with several SS's at various locations within the sector. All locations are again in obstructed line of sight, some only by minor foliage, some completely shadowed by buildings.

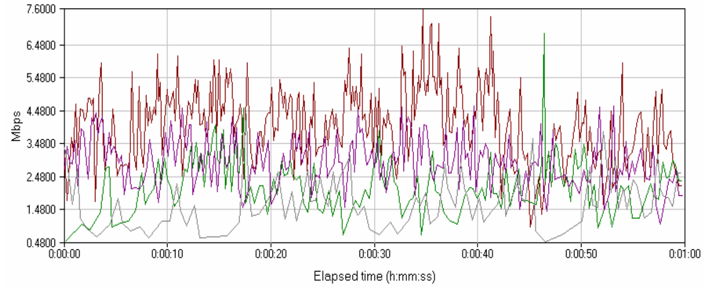

Fig. 11. Time varying throughput in Mbps for four simultaneous units during field testing.

Again we plot throughput vs. distance, but the graph must be considered with some attention: although each point shows actual customer throughput, one must keep in mind that simultaneous customers were present, and therefore this throughput could be optimized and increased by separately providing additional resources to a specific location where service is poor.

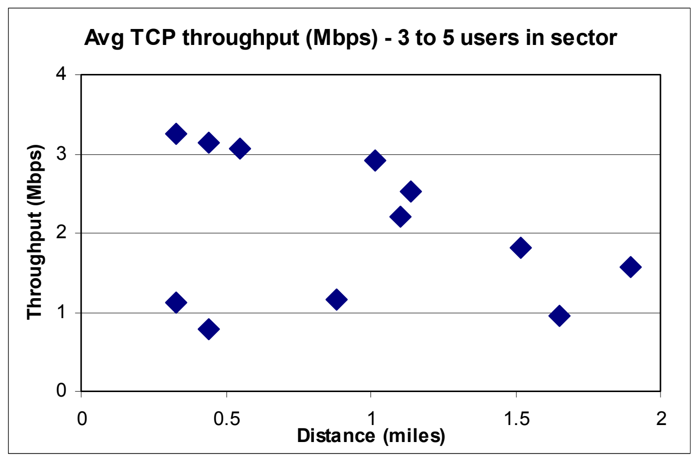

Fig. 12. Average throughput in Mbps for various locations within a sector in actual field testing (3 to 5 users).

3) *Throughput Distribution*

Throughput is given here for the entire sector, in different conditions of use: one to many SS in various locations. For comparison with the lab distribution, cumulative distribution functions are then derived for the entire sector in all the above cases. This distribution function is slightly more irregular, which was to be expected since the modulation was allowed to be changed by the BS, such a choice was required in order to adapt to different link conditions among the several simultaneous SS's.

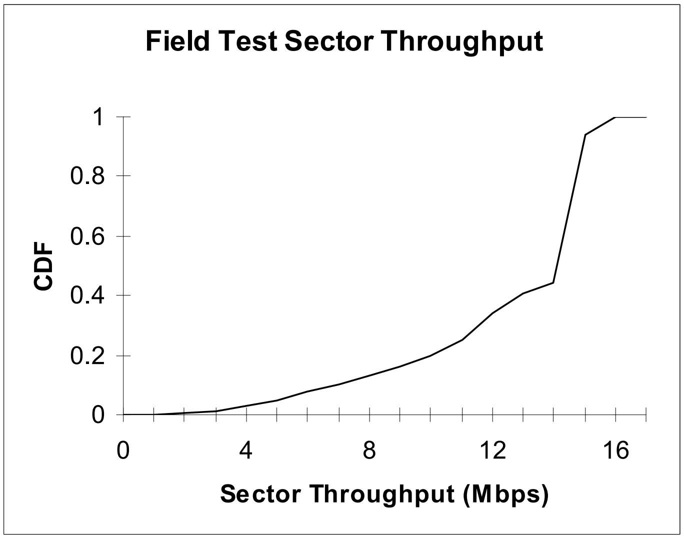

Fig. 13. Cumulative distribution of average sector throughput, SS's in various locations in a suburban area.

4) *Throughput and SNR*

Because locations greatly change link quality depending on obstructing trees or buildings a better prediction for performance is given by SNR measurement on location; in which case a simple correlation rule may be derived (given a number or simultaneous active users). Of course in many cases it is impractical to survey and measure SNR at potential customer locations, but wherever possible such a survey provides precious additional help for prediction of service performance.

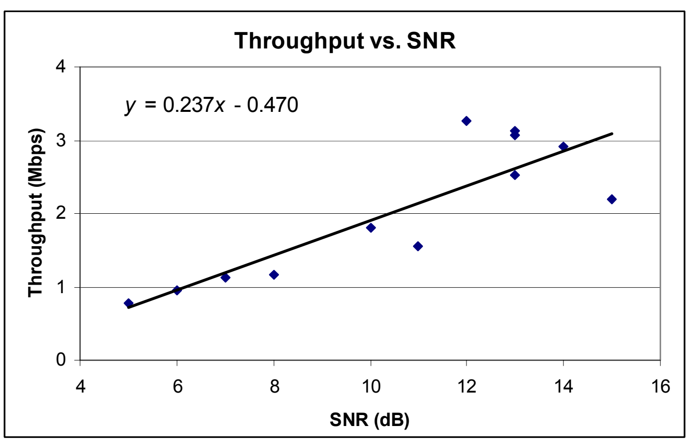

Fig. 14. Average throughput in Mbps for SNR measured on various locations within a sector in actual field testing (3 to 5 simultaneous active users).

5) *Different Protocols*

Finally we study the throughput of various protocols widely used in data services: TCP and UDP throughput, and also data transmitted by http and ftp protocols. Actual average data rates are compared for several locations of one single unit, and for the total base station throughput when 3, 4, or 5 subscriber stations are used simultaneously.

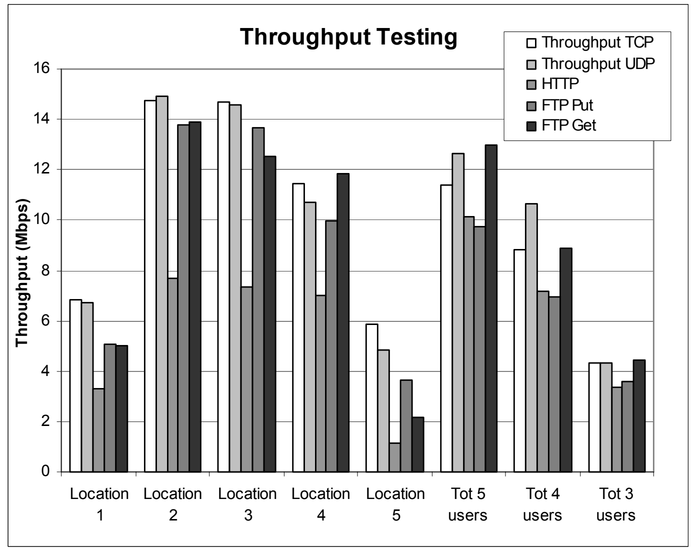

Fig. 15. Bit rates of various protocols measured for one unique subscriber in location 1 to 5, and for the sum of several (3, 4 and 5) simultaneous SS's in various locations.

Throughput with one SS in different locations throughout the sector show good results in spite of obstacles such as trees, homes and urban traffic. Location 1 and 5 in particular were chosen to be much obstructed links (behind buildings) and still showed a fairly reliable link, although with much lower throughput. When Several SS's are combined in one sector, the overall average throughput remains good in spite of poor links for some units.

CONCLUSION

This study focuses on measuring data throughput of radio equipment in various channel models and at diverse data modulations and encoding rates. It presents test results in different SUI channel models as well as in actual field tests. The comparison between SUI model distribution functions does not allow us to determine which one best fits our field data because data results are so close; but our results show on Figure 16 that field tests conducted in a suburban area are well approximated by certain lab results.

The SUI-3 & 5 models seem to be acceptable models with which to approximate our field data (although further analyses should be conducted to see which of the two is the best fit), and overall throughput for the sector resembles most (but is slightly worse than) lab results with 16QAM in SUI-3 (or 5) conditions. In all cases field results fit well between QPSK and 16QAM modulations.

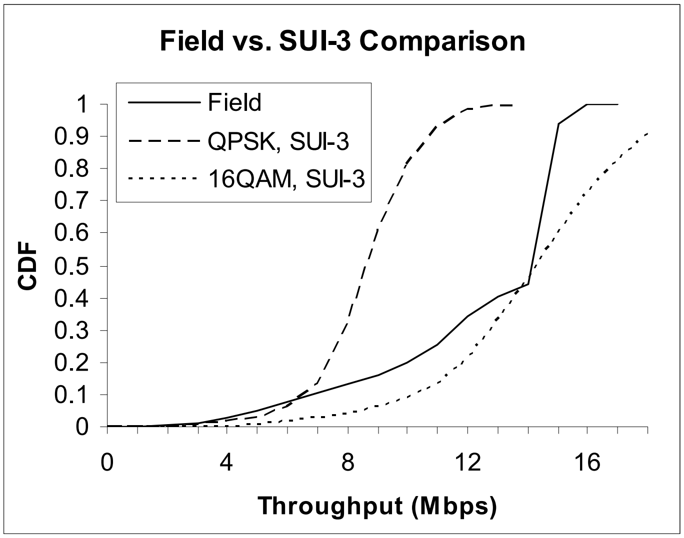

Fig. 16. Comparison of field test distribution with lab result distributions for SUI-3 channel model and QPSK or 16QAM modulations.

Consequently, as service providers chose fade margins, propagation estimates, capacity estimates, in their link budgets for the rollout of fixed data services using 802.16-2004 radios, in suburban areas, these results recommend using approximations consistent with SUI-3 or 5 and 16QAM modulation.

REFERENCES

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[2] IEEE 802.16 Broadband Wireless Access Working Group, "Channel Models for Fixed Wireless Applications" Contribution to 802.16a, 2003, available at http://wirelessman.org/tga/docs/80216a-03_01.pdf.

[3] V. Erceg et al., "An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments", IEEE Journal on Selected Areas in Communications, Vol. 17, No. 7, July 1999.

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