

Convergence of Cellular and Wireless LAN: Hotspot Traffic Statistics and User Trends

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3G Stumbles – 802.11b Leaps

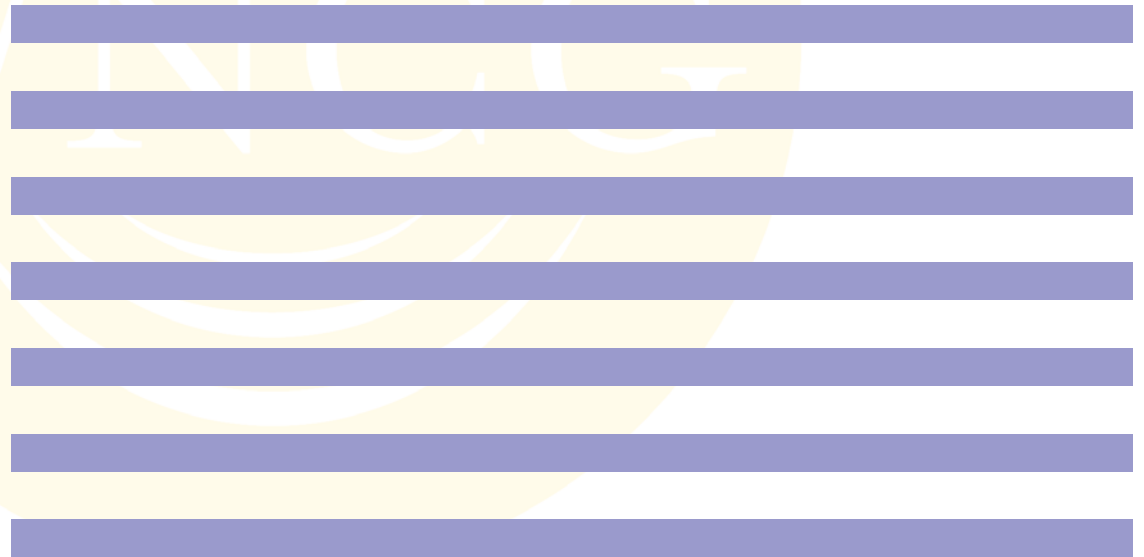
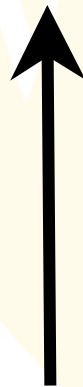
- Wi-Fi exploits Internet data rates while 3G was developed before Internet popularity
- GSM dominates worldwide cellular/PCS – but has tough 3G upgrade economics
- CDMA networks have smoother road to provide wireless data, but still expensive to get good data rates
- opportunity is ripe for converging technologies to provide wireless data
- success of 802.11b shows demand for wireless data is real: Dell, Intel, Hotspots!

Traffic Pattern Evolution

Voice Traffic

Style: continuous low data rate for many users at once

users and
data rate

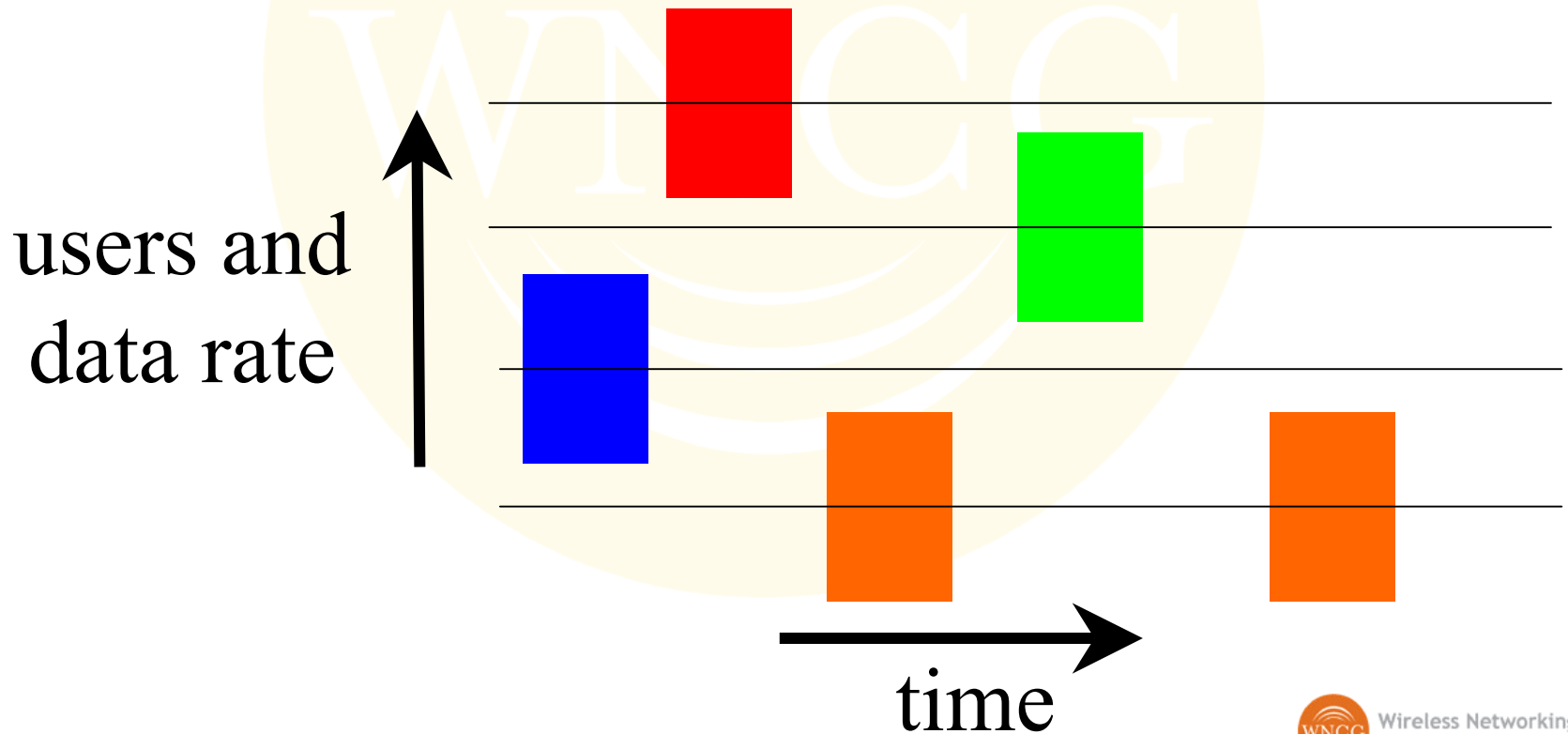


time

Traffic Pattern Evolution

Data Traffic

Style: occasional high data rate usage from each user



Optimizing for Voice vs. Data

- **3G cellular/PCS** networks optimized for voice traffic, struggling to maintain those optimizations while increasing data rates
- **802.11** optimized for data, struggling to provide quality of service for VoIP

Optimizing for Crowds vs. Mavericks

- **3G** networks optimized for handling crowds of voice callers, struggling to provide high speed data to occasional data callers
- **802.11** networks optimized to provide high speed data to occasional data callers, struggling to deal with interference in crowded environments
- **neither 3G nor 802.11 provides high speed data in crowded environments!!!!**

802.11 vs. 3G

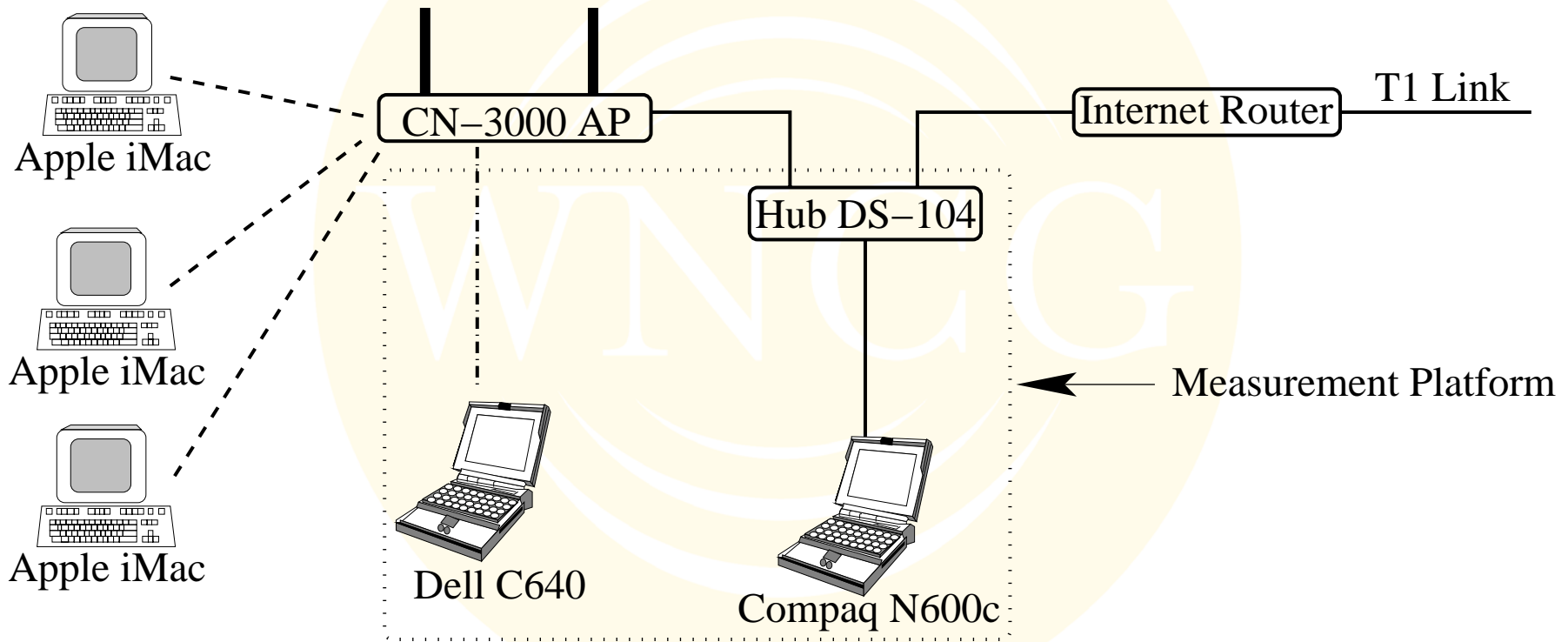
Feature	802.11b	3G
data rate	6 Mbps	2 Mbps
coordinated multiple access	NO	YES
guaranteed bandwidth	NO ^e	YES
dynamic channel assignment	NO ^h	YES
dynamic gain control	NO ^h	YES
security	NO ⁱ	YES
roaming	NO ^f	YES

*superscripts indicate IEEE 802.11 standard under development e.g. 802.11 e

Schlotzsky's Cool Cloud Traffic and Throughput Research Project

- Free wireless access to the Internet
- Based on the IEEE 802.11b standard
- Studied four distinct real-world hotspots
- Real-world public hotspot traffic statistics
- Throughput measurements
 - IEEE 802.11b cards from two vendors: Cisco and ORiNOCO
 - Three representative applications

A Typical Schlotszsky's Hotspot



Schlotszsky's Lamar restaurant (IEEE 802.11b network)

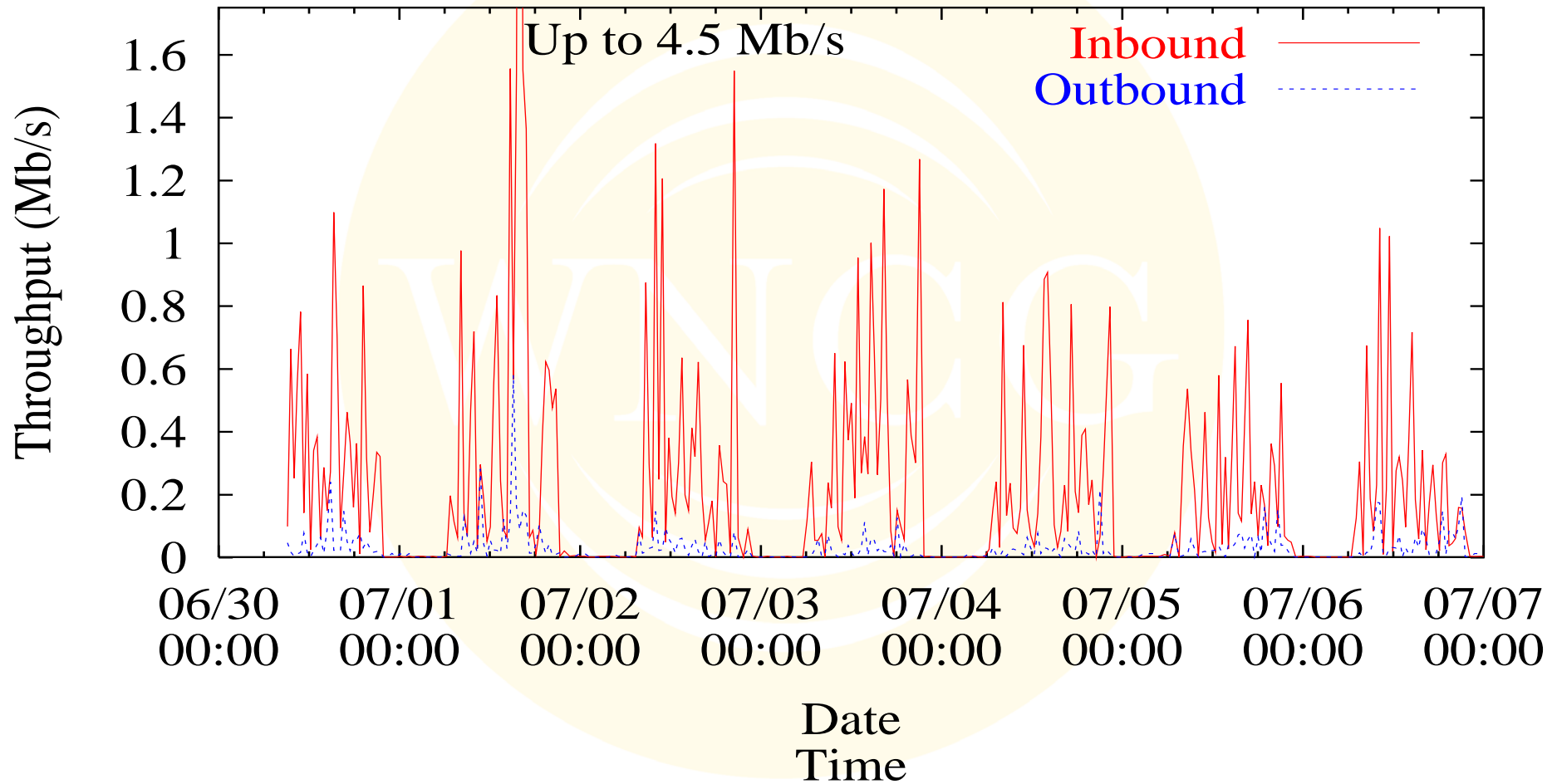
Hotspot Measurement Approaches (I)

- Studied hotspot network in 3 Schlotzsky's restaurants
- Considered multiple Wi-Fi users (controlled)
- Considered various T-R separations
- Considered 3 real-world applications
 - Wireless Valley LANFielder
 - FTP
 - Iperf

Hotspot Measurement Approaches (II)

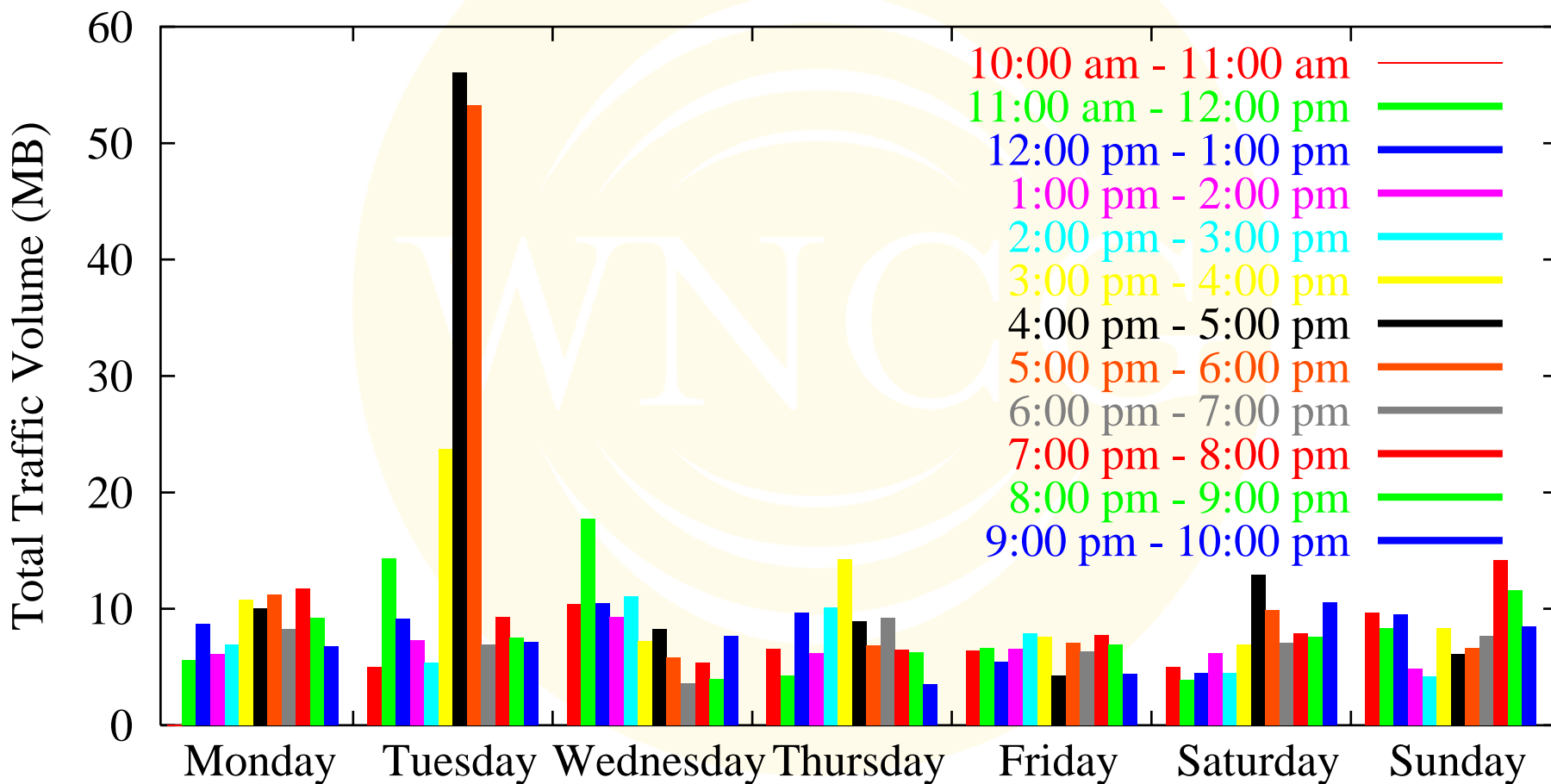
- Traffic statistics in live hotspots
 - One week continuous data were measured
 - Schlotzsky's Lamar restaurant (Austin, TX)
 - Sniffer computer after AP: Compaq N600c
 - Log *all* packet headers to and from the hotspot
 - Valuable real-world hotspot traffic statistics

Overview of Weekly Hotspot Traffic



From: C. Na, J. Chen, and T. S. Rappaport, "Measured Traffic Statistics and Throughput of IEEE 802.11b Public WLAN Hotspots with Three Different Applications", Submitted for publication in February 2004

A Closer Look of Hourly Traffic



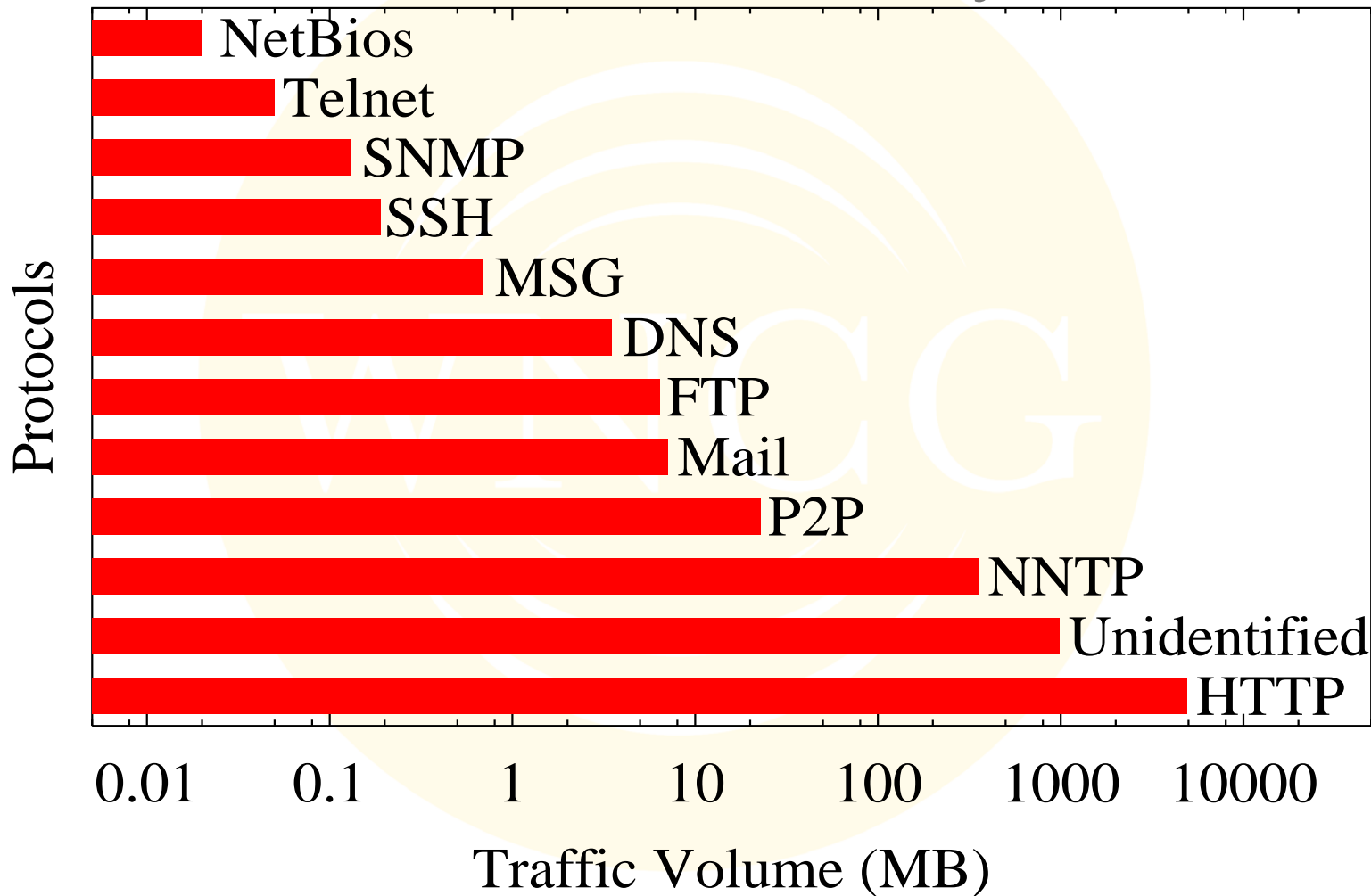
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Traffic Volume Over One-week Period From June 30 to July 7, 2003

	<i>Bytes</i>		<i>Packets</i>	
	<i>GB</i>	<i>%</i>	<i>M</i>	<i>%</i>
<i>Total</i>	6.3	100	13	100
<i>Inbound</i>	5.3	84	6	46
<i>Outbound</i>	1.0	16	7	54

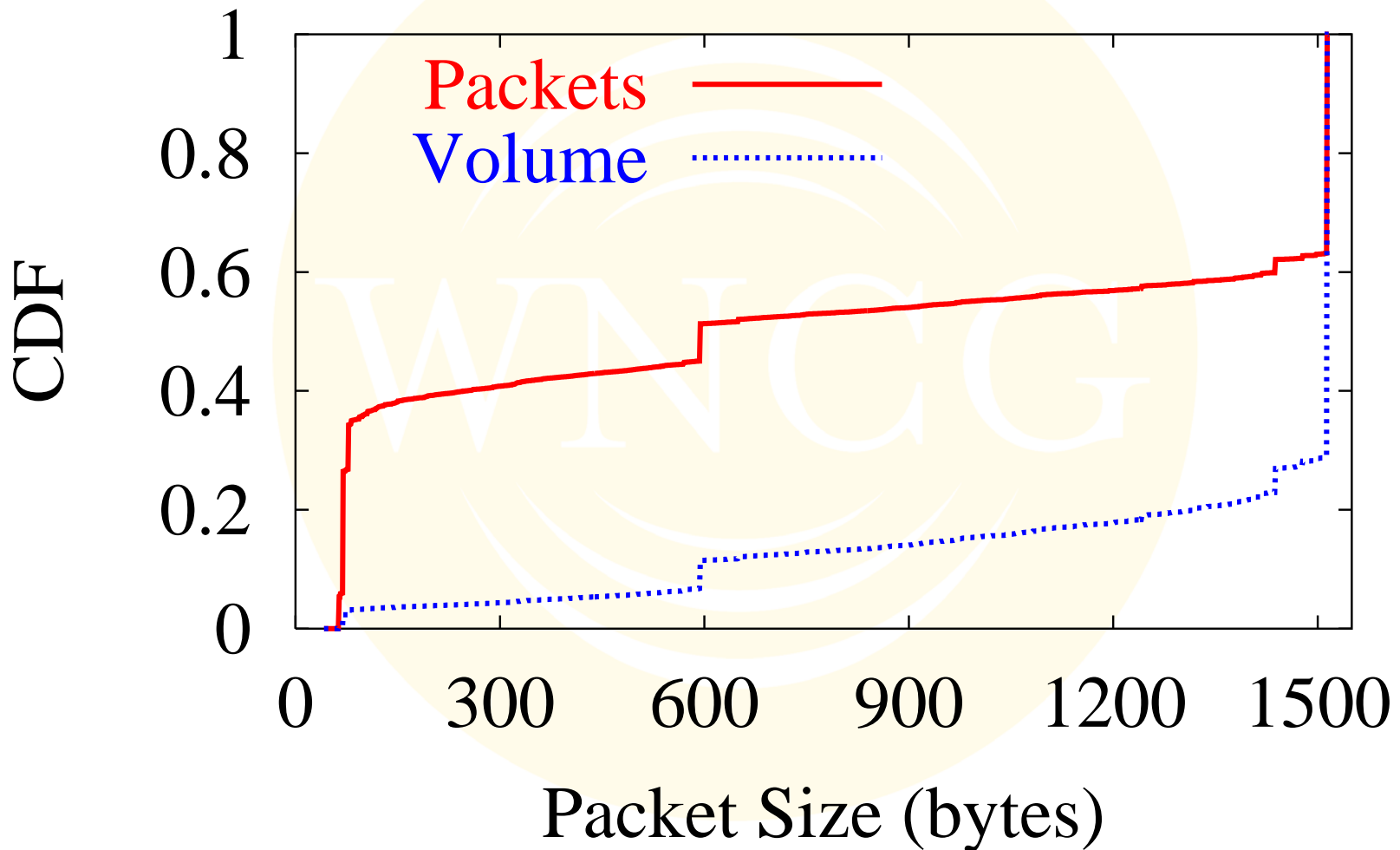
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Application Distributions Over One-week Period From June 30 to July 7, 2003



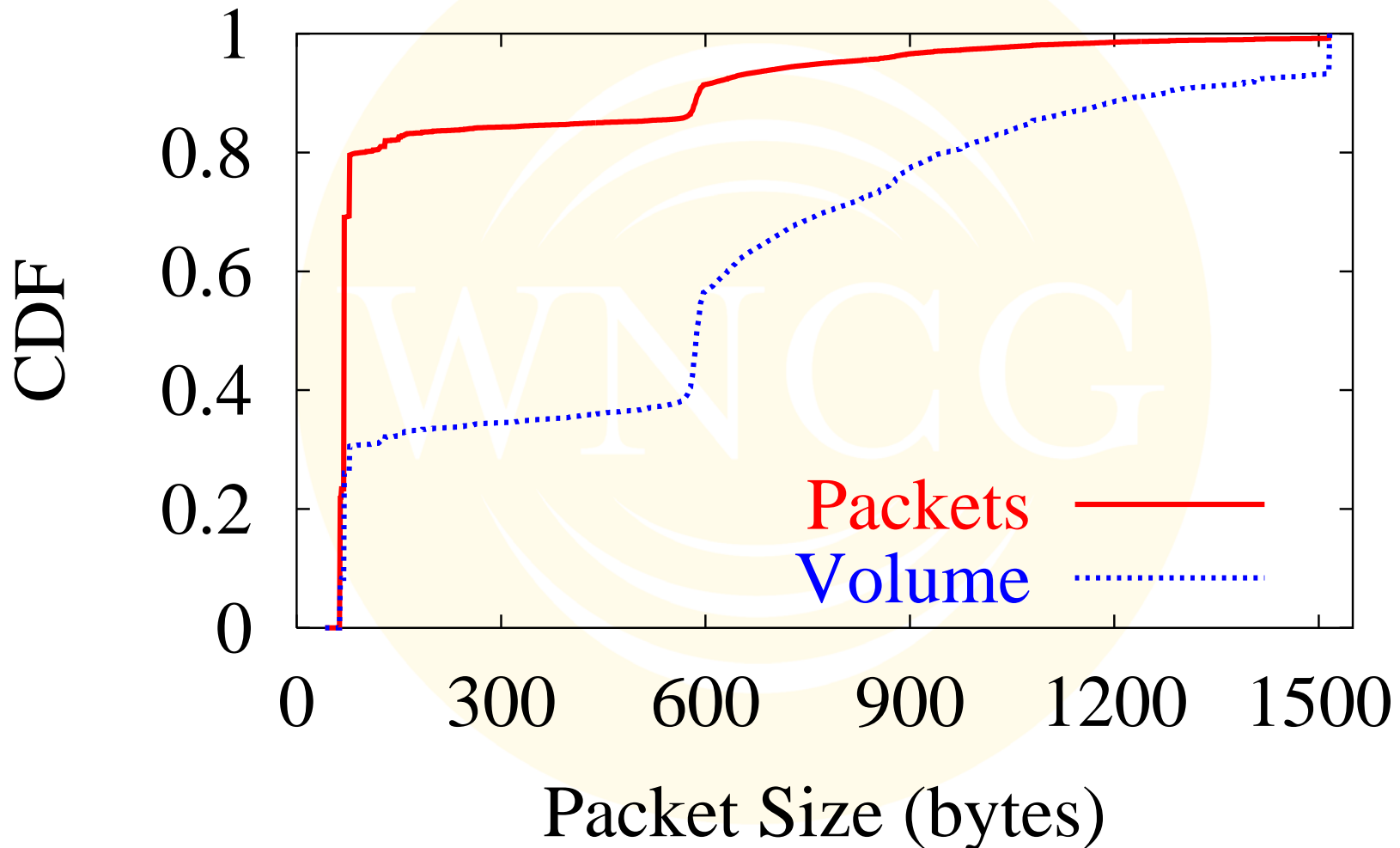
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Inbound Packet Size Distribution



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Outbound Packet Size Distribution



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Characterizing Typical Hotspot Traffic Statistics

- Hotspot service attracts customers to stay
- Total traffic load is not necessarily proportional to the number of users
- More downloading activities than uploading (1:5)
- Distinct inbound/outbound packet size distributions
- HTTP still dominates
- Real-time autonomous control mechanisms will become critical

Modeling Application Throughput for Inbuilding Wireless Applications

- Controlled Wi-Fi tests revealed accurate models for predicting and verifying user application throughput
- Three applications used to validate approach
- Wireless Valley LANFielder useful for emulating future real-time UDP data (VoIP, VoD)
- Iperf and FTP used for today's applications

The Piecewise Model to Predict and Measure Application-specific Throughput

$$T = \begin{cases} T_{\max} & SNR > SNR_c \\ A_p \times (SNR - SNR_0) & SNR \leq SNR_c \end{cases}$$

Saturation throughput

Slope

Cutoff SNR

Critical threshold

From: C. Na, J. Chen, and T. S. Rappaport, "Measured Traffic Statistics and Throughput of IEEE 802.11b Public WLAN Hotspots with Three Different Applications", Submitted for publication in February 2004

The Exponential Model to Predict and Measure Application-specific Throughput

$$T = T_{\max} \times (1 - e^{-A_e \times (SNR - SNR_0)})$$

Saturation throughput

Saturation rate

Cutoff SNR

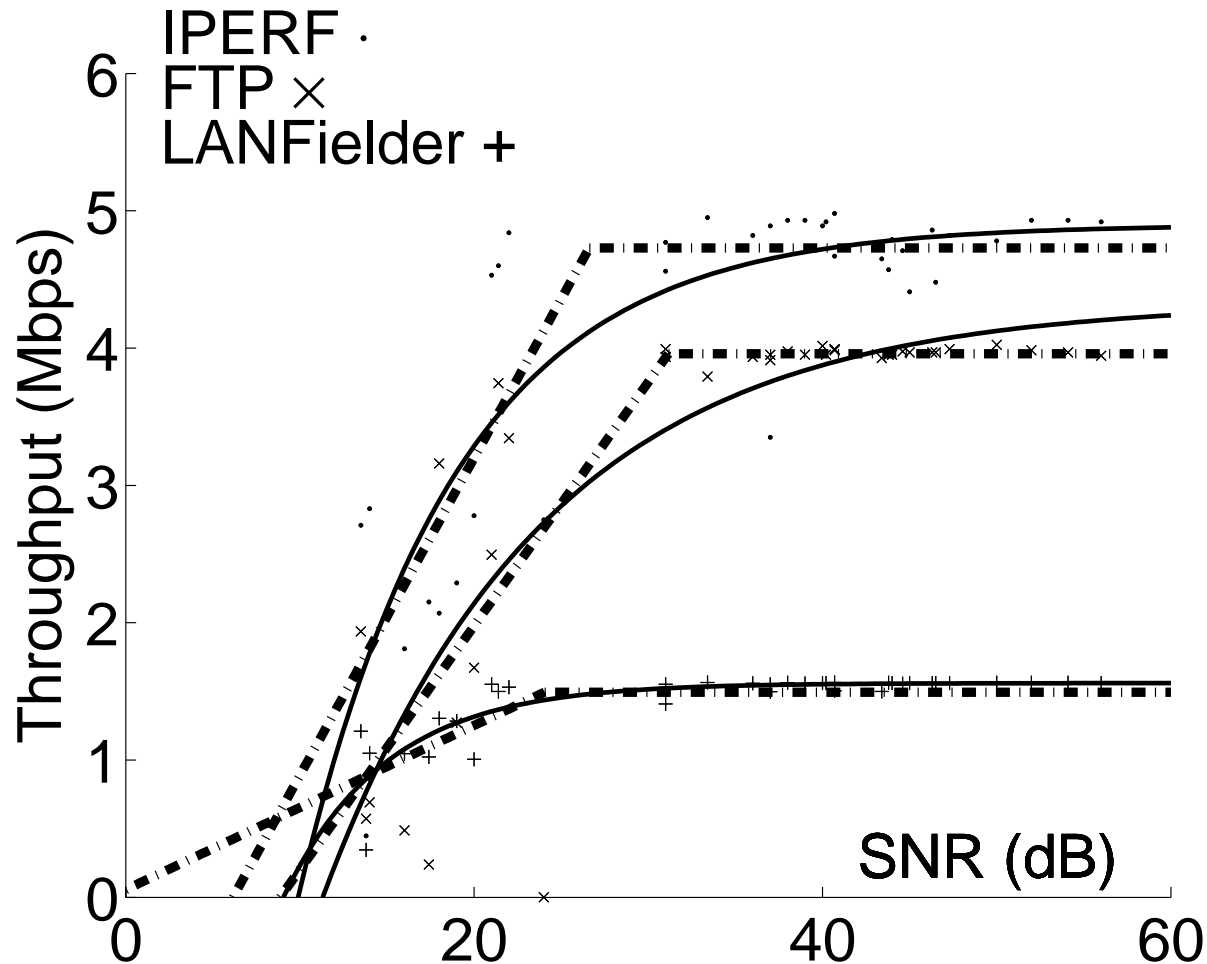
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Typical Model Parameters

	Piecewise			Exponential		
	T_{\max} (Mbps)	SNR_c (dB)	SNR_0 (dB)	T_{\max} (Mbps)	A_e	SNR_0 (dB)
Iperf	4.73	26.6	6.16	4.90	0.11	9.90
FTP	3.96	31.2	8.86	4.33	0.08	11.3
LANFielder	1.49	24.0	-0.94	1.56	0.17	9.04

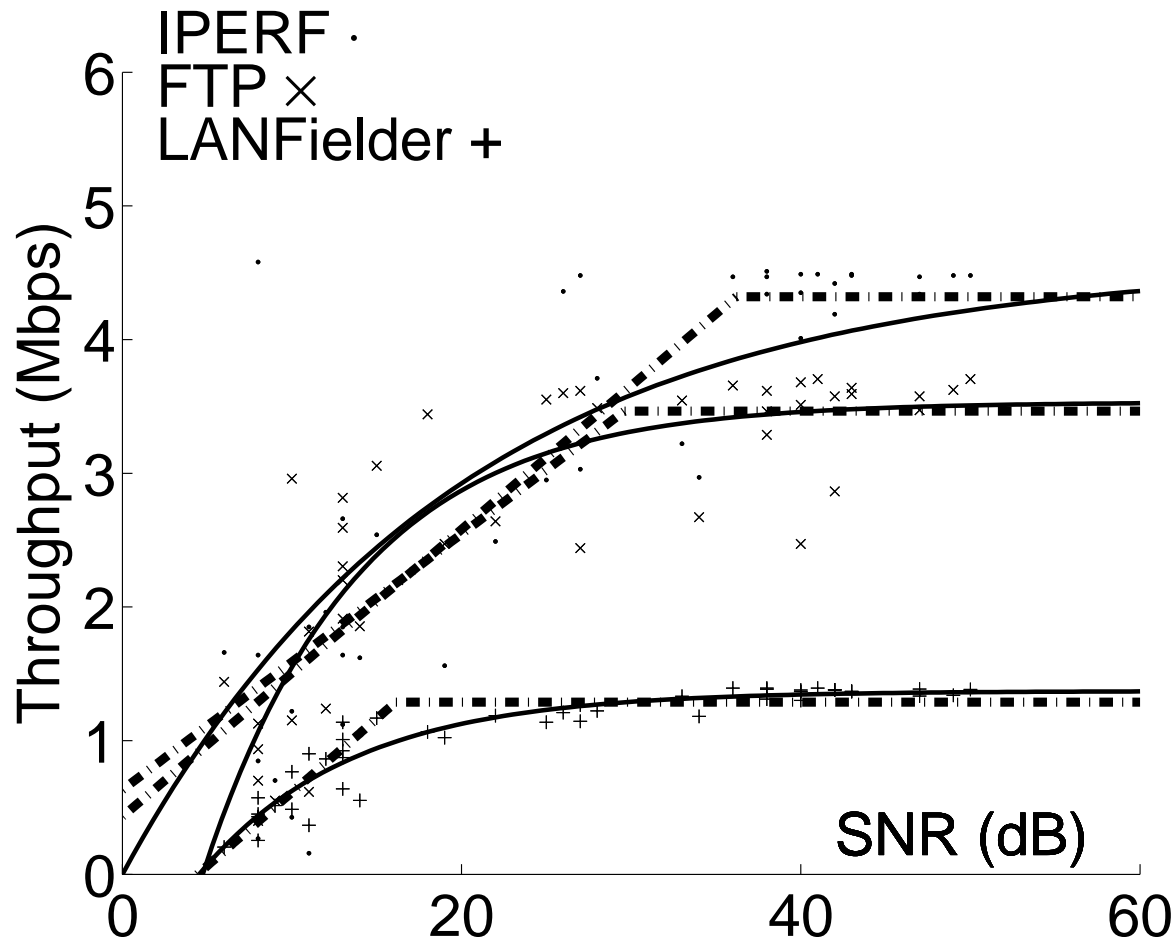
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Throughput and SNR Values Measured at Schlotzsky's Parmer Restaurant Using Cisco Card



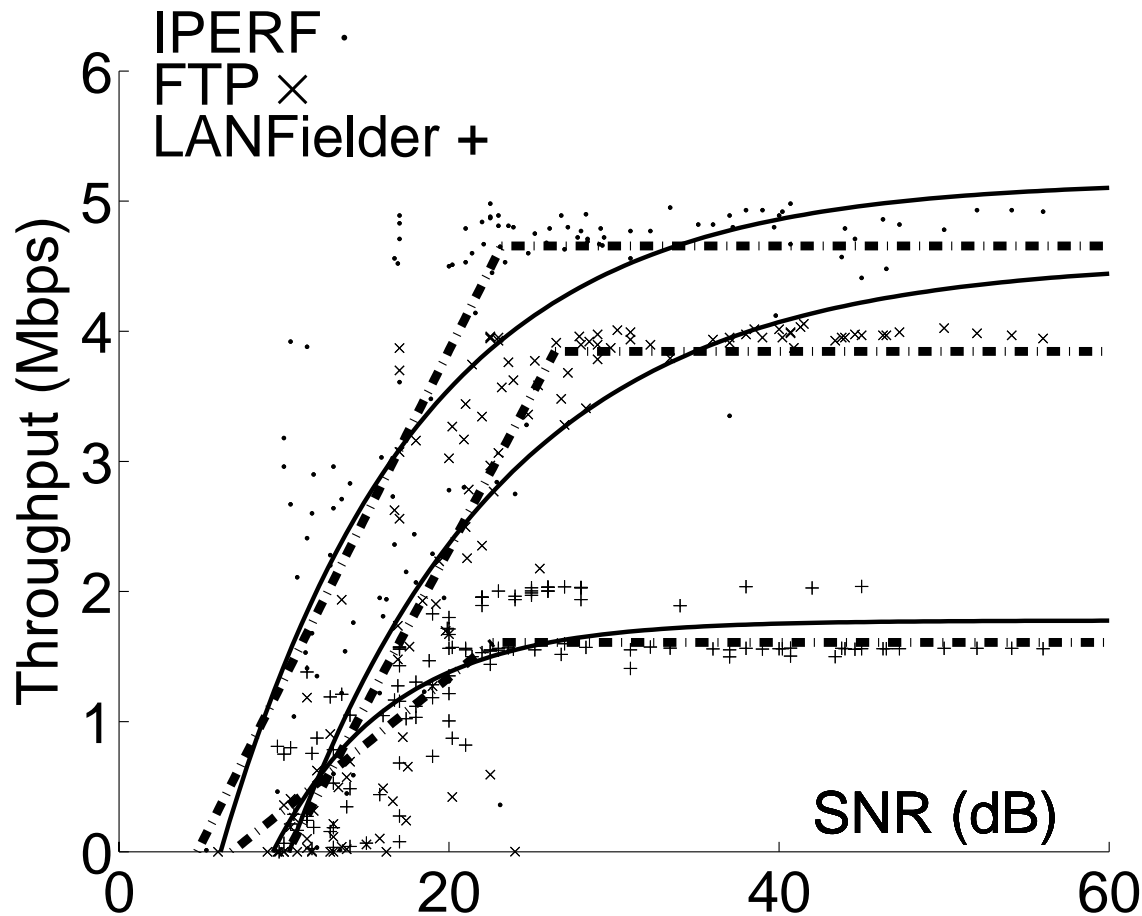
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Throughput and SNR Values Measured at Schlotzsky's Parmer Store Using ORiNOCO Card



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Throughput and SNR Values Measured at Three Schlotzsky's Restaurants Using Cisco Card



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Throughput Prediction Models

- Empirically based throughput prediction models are very accurate across applications
 - Correlation coefficient $> 80\%$ in most cases
- IEEE 802.11b throughput values
 - Hardware specific
 - Application specific
 - Maybe not location specific
 - Despite this, proposed models are accurate for all cases
- Convergence of cellular and Wi-Fi will require accurate prediction and tuning of throughput models
- Wireless Valley has validated control and optimization techniques using site-specific information
 - More hardware implementations
 - More applications

Final Remarks

- Cellular started from the outside, and is moving inside buildings
- Wi-Fi started from inside buildings, and is moving outside
- We only use high data rates when sitting, standing or recreating in and around buildings
- A giant battle field for the last 100 m is up for grabs, and the Internet will drive convergence in favor of packet-based, not circuit-switched techniques
- This paper has presented insights into user behaviors and promising control mechanisms for future high-data rate inbuilding networks