

**Interference Cancellation as a  
Mobile Enhancement to Improve Spectral Efficiency**

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# Narrative Outline



- The Shannon Game is to trade power efficiency for spectral efficiency in the wireless network. To score in the game we need to match transmitters and receivers to the channel effects (interference). This impels us to understand:

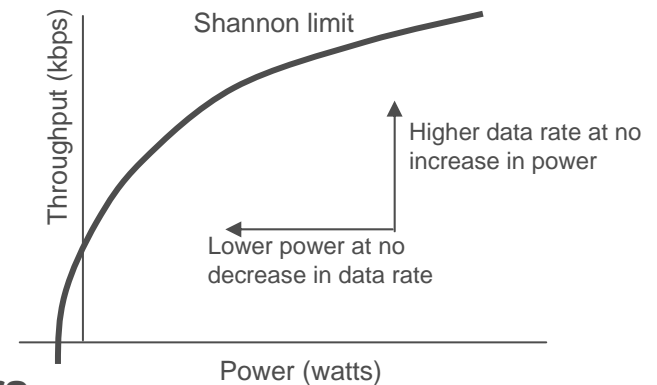
- Interference: Its sources and its effects

- Interference Cancellers

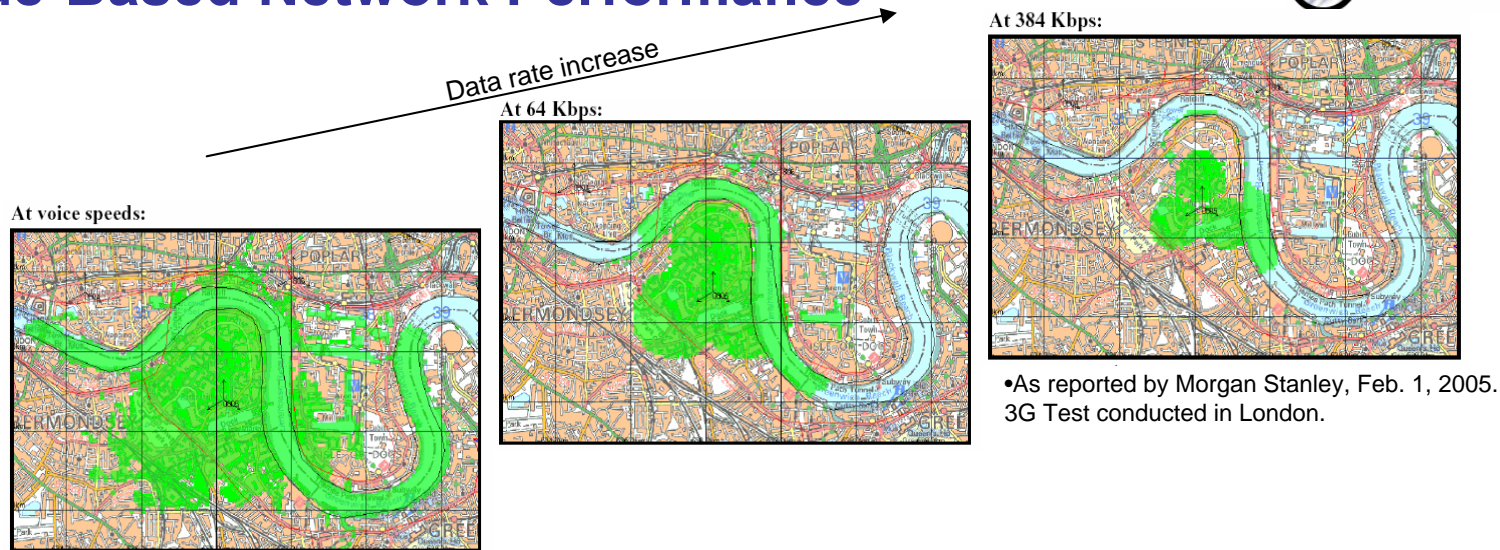
- Then we can analyze:

- Performance of Interference Cancellers

- Economic Impact of Interference Cancellers



# Interference is the Key Limiter of Code-Based Network Performance



## ■ Dramatic demonstration of the Shannon game:

- For increased data rates, only users near cell center have sufficient power, thus reducing effective cell size. So increase power. But this increases interference, producing no useful effect for power, unless an interference cancellation receiver is matched to channel.

## ■ Data rate and capacity reduction; Quality of service degradation

- Degraded reception leads to lower data transfer rates
- Majority of users effectively at edge of cell
- Interference causes base stations to broadcast more power to each terminal
- The number of terminals that can be supported simultaneously is reduced
- Increase in coverage holes leads to more frequent dropped calls

## Evolution of Interference Cancellation Receivers from CDMA2000 to 1xEV-DO and WCDMA/HSDPA



- Historically, interference cancellation for all channels has been considered too complex and costly to deploy. Key breakthrough is an interference cancellation solution that can be implemented within a baseband chip.
- There has been a belief that a PN-averaged equalizer bounds the performance of an advanced receiver for 1xEV-DO. Recent developments prove that this equalizer bound can be breached with interference cancellation.
- Interference cancellation integrates with receive diversity and extends to MIMO-OFDM.
- Interference cancellation for WCDMA/HSDPA is a study item in 3GPP RAN4. TensorComm is a participant and contributor.

## TensorComm's technology roadmap continues to improve gains of Interference Cancellation Technology (ICT™)



**ICT 220**

**Aug 04:** System simulations prove viability of ICT

**Nov 04:** ICT gains demonstrated in field trials on commercial CDMA2000 network using integrated FPGA platforms

**March:** Operator proves substantial capital savings in network capacity and performance

**April:** Publicly announce ICT

**July:** Extend solution to WCDMA.

**November:** Announce next generation ICT for 1xEV-DO and HSDPA

**ICT 440**

**Jan:** ICT 440 data throughput increases of 50%+ proven in system simulations

Gains up to 6 db

**Feb:** Results submitted to 3GPP

Requested by operators to conduct network trials

•Improvements to dB gain; size reduction

•S-DMB applications

•Base station solution

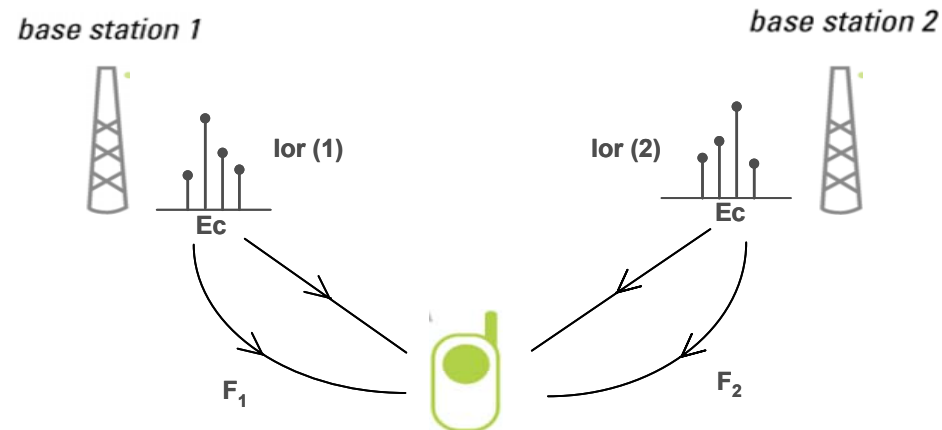
•MIMO-OFDM solution

TensorComm continues to fortify its Intellectual Property and to conduct evaluations in cooperation with operators and chipset vendors

## Characterizing Interference

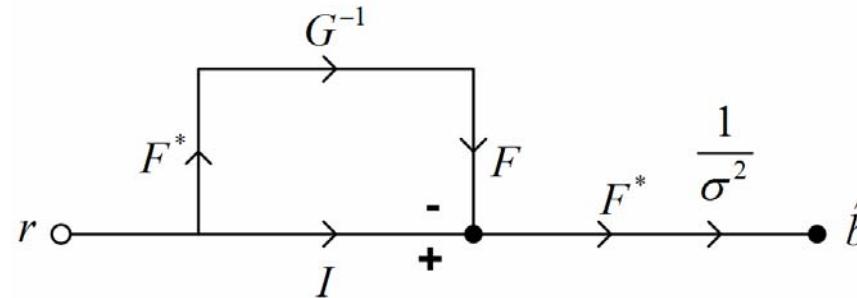


- Channel effects defeat all attempts to maintain the orthogonality between coded sub-channels in a multi-access system. As a consequence there is interference between sub-channels, and it comes in two varieties:
  - intra-cell interference due to multi-path structure
  - inter-cell interference due to interfering base stations



- The problem is particularly problematic when coded sub-channels are densely populated and/or the mobile terminal finds itself in an edge of cell condition. The technology challenge is to cancel these effects, at manageable complexity, in order to maintain cell size and/or increase data rates.

# A Representation of Advanced Receivers



$G^{-1}$	Advanced Receiver
0	RAKE
$(F^* F)^{-1}$	Projector or Decorrelator
$(\sigma^2 I + F^* F)^{-1}$	Symbol Rate LMMSE Receiver
$(\sigma^2 I + \overline{F^* F})^{-1}$	Doppler Rate LMMSE Equalizer
$(G^{-1})$	ICT

$F$  : synthesis       $F^*$  : analysis

$$F = [F_1, F_2]$$

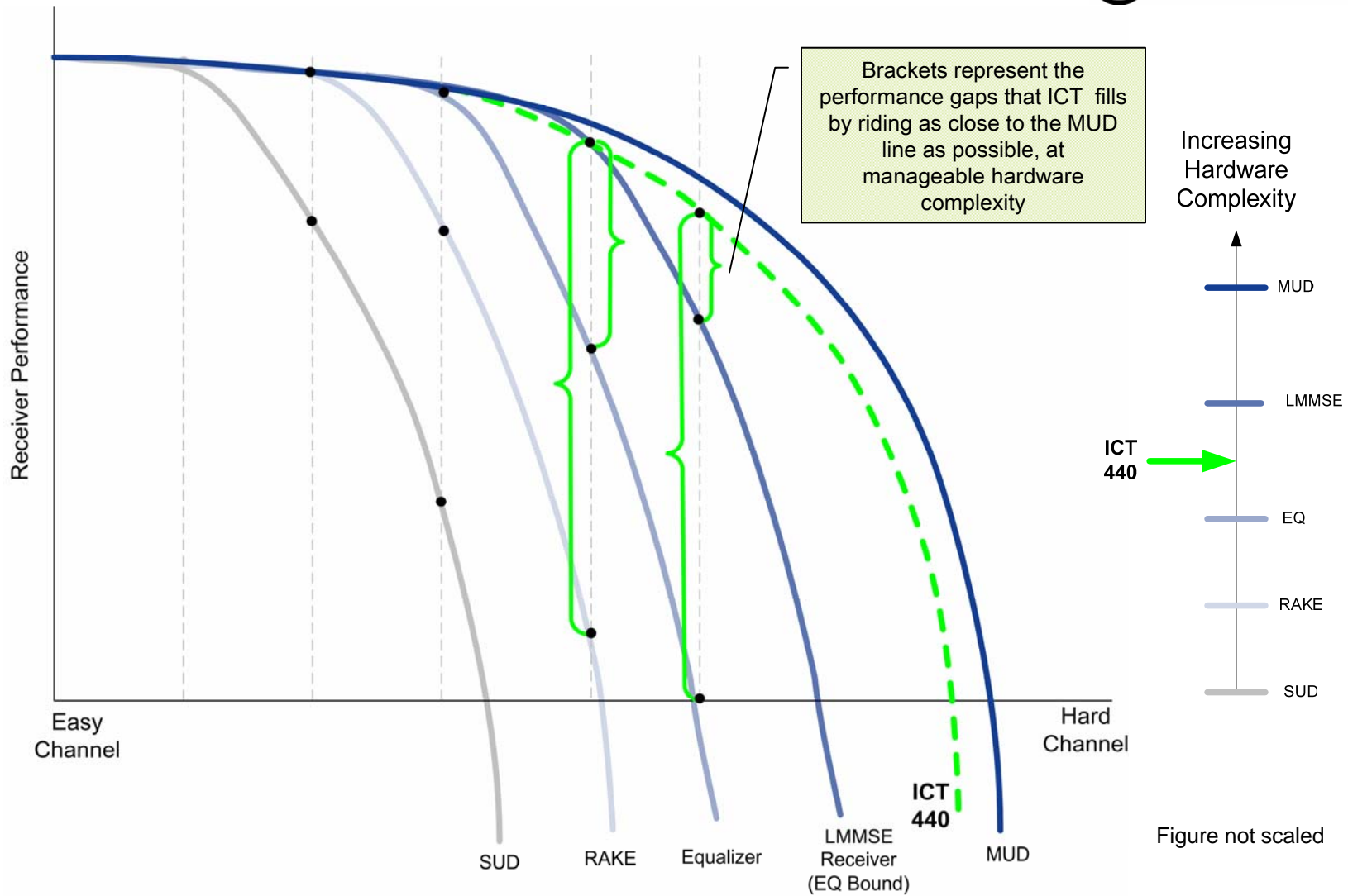
## Characteristics of Advanced Receivers



	RAKE	Equalizer	ICT
Matches to intra-cell multi-path	√	√	√
Matches to inter-cell multi-path	√ (in soft hand-off)		√
Manages intra-cell code correlation		√ (@ doppler rate)	√ (@ symbol rate)
Manages inter-cell code correlation		√ (@ doppler rate)	√ (@ symbol rate)

- Only ICT matches to inter-cell and intra-cell interference, at the symbol rate.
- ICT removes interference from all channels (not just pilot).
- ICT fills performance gaps that arise between RAKEs, equalizers and MUDs.
- ICT subsumes equalizers, and it fits within the architecture of a RAKE receiver, with no impact on RF design.
- ICT integrates with MRD.

# ICT Fills Performance Gaps



## ICT Increases User Data Throughput



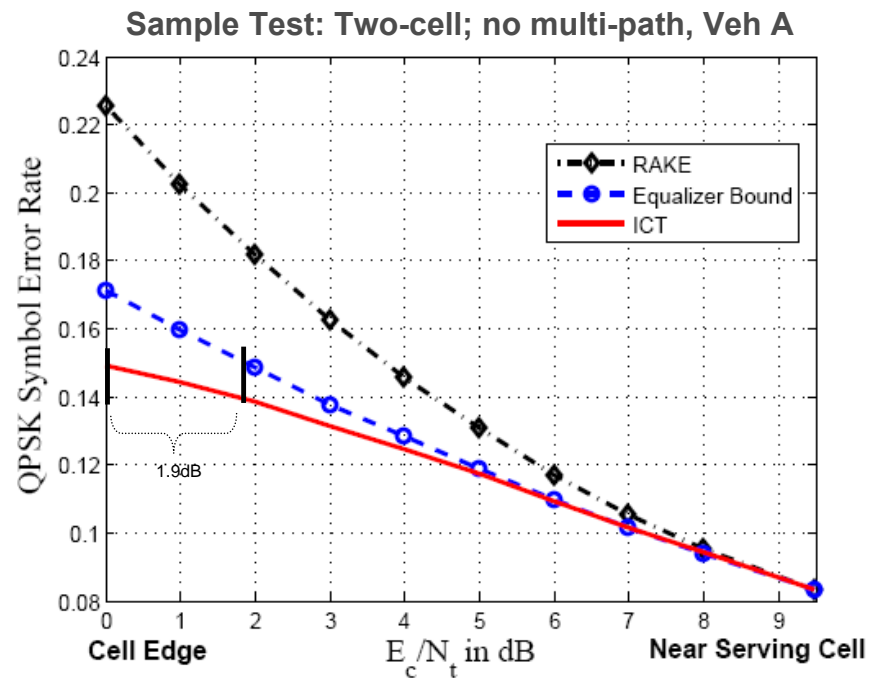
HSET_6 QPSK Mid Geometry (Ior/Ioc = 5 dB) 2 Basestations, 1 Interfering Ec/Ior = -6 dB for HSDPA (10-code)	User Throughput (kbps)		% Increase in User Throughput
	Pedestrian B	Vehicular 30km/hr	Average ICT Gain Over
Current Receiver (RAKE) *	433	595	270%
Type 2 Future Receiver (LMMSE equalizer)	976	988	90%
Type 1 Dual Antenna Receiver (RD)	1181	1220	55%
Type 3 (RD + LMMSE equalizer)	1651	1674	
<b>TensorComm ICT **</b>	<b>1825</b>	<b>1899</b>	

- TensorComm has completed extensive link-level simulations conducted in conjunction with multiple WCDMA chipset vendors.
- These comparisons are conservative because RAKE, equalizer and RD use AWGN model for interfering base stations.
- A sample of similar results included in contribution to 3GPP : RAN4 document number R4-060043.

\* Rake by itself will not provide meaningful data throughputs. For many channel conditions and geometries, advanced receivers will be necessary for any realistic applications beyond voice.

\*\* Interference is modeled as a true node B, per 3GPP 25-101

## ICT Optimized for 1xEV-DO Data Networks



- Live data collects from U.S. 1xEV-DO markets indicate opportunity for ICT gain over RAKEs and equalizers in more than 60% of network conditions.
- When gains are averaged over observed network conditions, the sector throughput gains are increased by more than 40%.

# ICT Gains for CDMA2000 1X



Test Case	Test Environment Description	Interfering Number of Paths / Sectors	Channel Condition	ICT Gain (dB)
A	Cell edge, 44 of 64 users	2 / 2	Type I	4.7 dB
B	Cell edge, 64 of 64 users	2 / 2	Type I	2.4 dB
C	Mid cell, 44 of 64 users, unequal pilots (0, -6dB)	2 / 2	Type I	4.8 dB
D	Cell edge, 44 of 64 users	4 / 2	Type II	3.5 dB
E	Cell edge, 3 way softhandoff, 44 of 64 users	6 / 3	Type II	2.0 dB
F	Cell edge, 44 of 64 users	4 / 2	Type III	2.1 dB

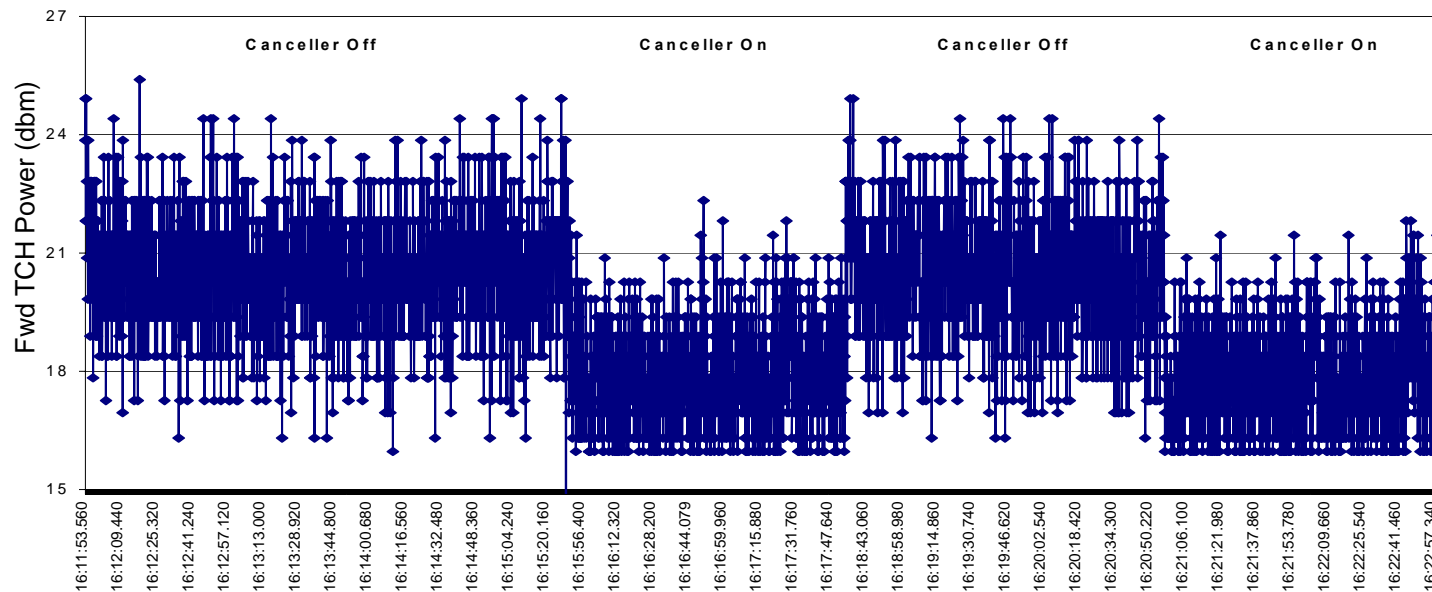
- Test cases are representative of interference-limited network scenarios derived from field data for a near capacity network :
  - Moderate to heavy loading
  - Cell edge
  - Multi-path and fading
  - Multiple sectors

Channel Condition	Definition
Type I	Stationary; non-fading
Type II	30 km/hr; Path profile=[0,-3]
Type III	100 km/hr; Path profile=[0,-3]

# ICT Trials Conducted in a Major Operator's Controlled Laboratory with Live Base Stations



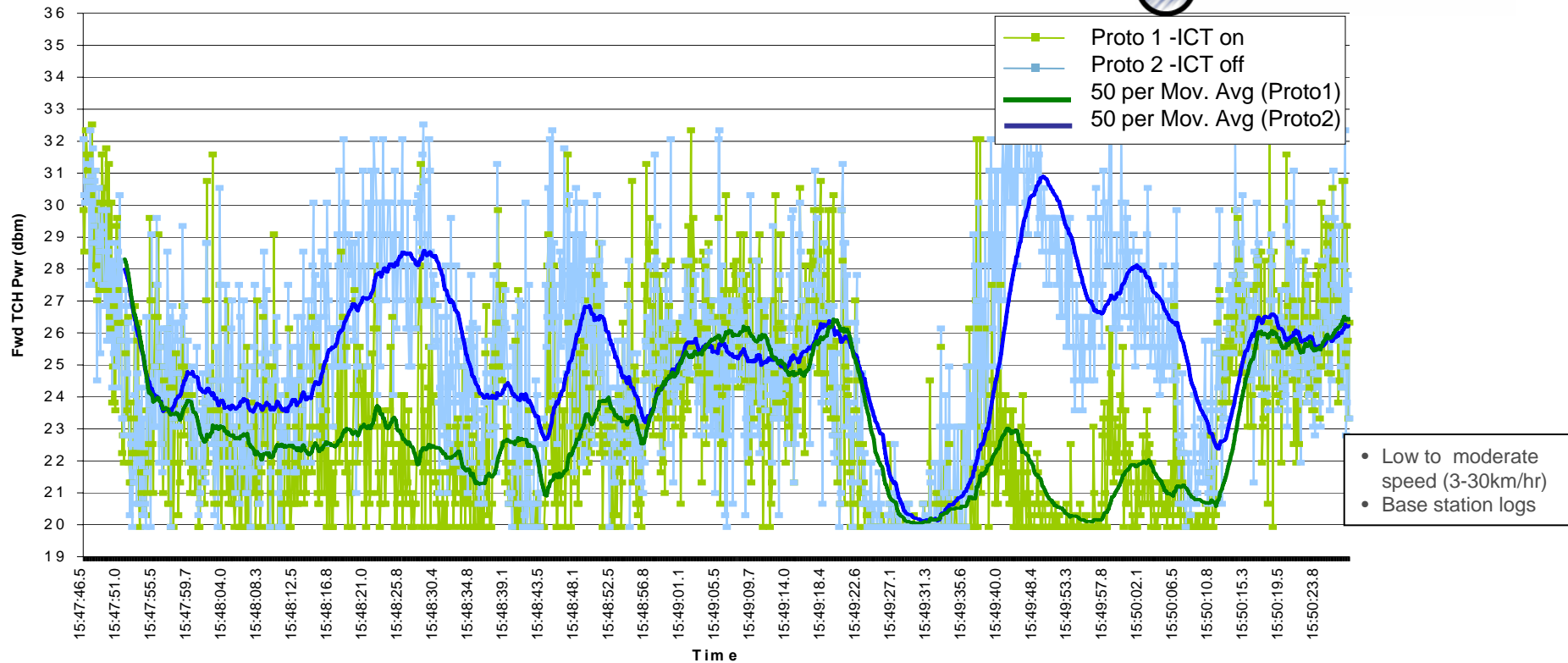
Forward Traffic Channel Power vs. Time  
75% OCNS



- Operator's controlled laboratory configuration consisted of a two-sector, live base station and fading simulator.
- ICT 220 prototype manually switched between ICT220-enabled and disabled modes during the call.
- Logs capture the base station power transmitted during the call.

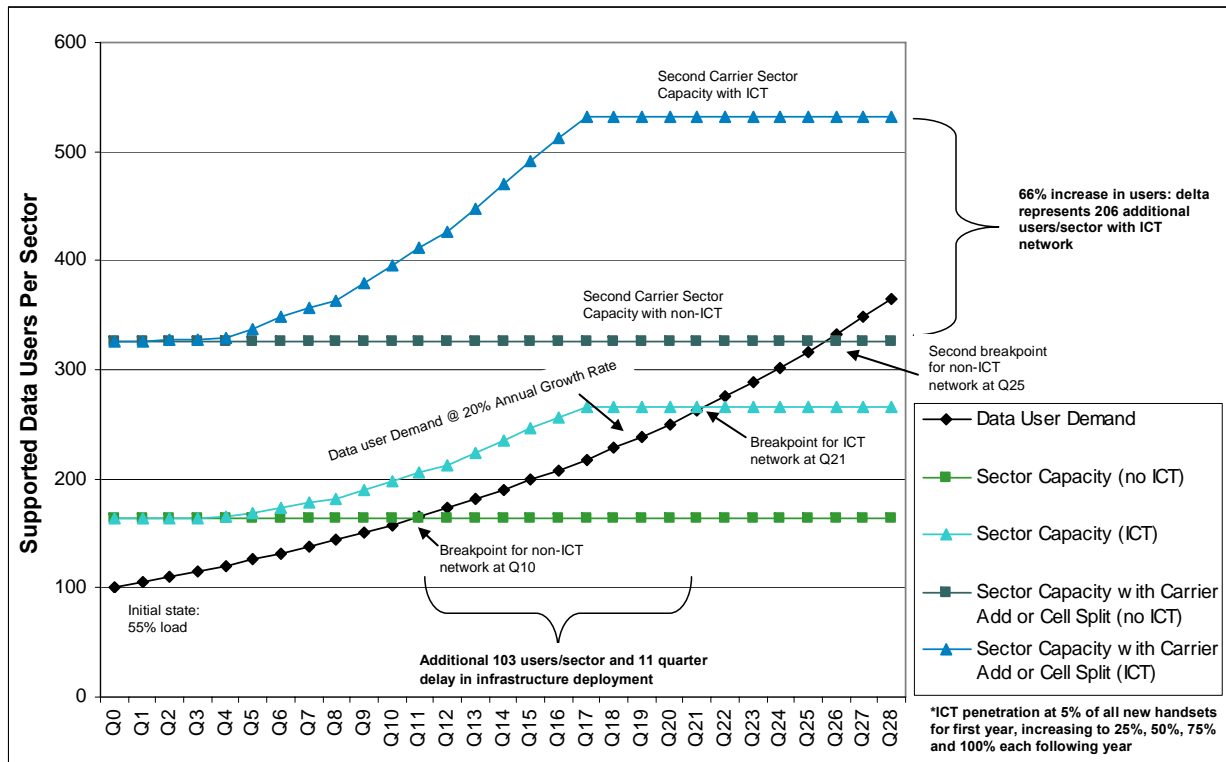
**ICT-enabled devices draw less power from the base station**

# ICT Proven on a Commercial CDMA2000 Network



- Evaluated on a major operator's commercial network on a handset designed by one of the world's top manufacturers.
- Base station power reduction when the network needs it the most, with edge case gains, particularly in blocking situations, of up to 6dB.
- Over 60% gain in network capacity.

# Operators Can Derive Dramatic Economic Benefits with ICT



## ICT gain translates into delay of network infrastructure

- Each incremental ICT-enabled terminal provides a benefit to the consumer and operator.
- Provides no less than \$30 benefit per handset
- Additional spectrum expansion delayed or eliminated

## ICT Derives Significant Gains for 3G Data Networks



- **Code-based systems are interference limited.**
- **Gains from interference cancellation are variable with network and channel conditions... in realistic channel conditions, up to 6 dB and an increase in user data throughput no less than 50%.**
  - Higher data throughput to user
  - Higher network capacity
  - Reduced base station power (and interference)
  - Fewer dropped calls in heavily loaded networks
  - Wider coverage area

## ICT Derives Significant Gains for 3G Data Networks



- ICT outperforms equalizers, is comparable to MRD, and approximates MRD plus equalizers, at a fraction of the cost.
- ICT is a hardware efficient design, ready for integration and optimized for data networks. ICT has been proven in simulations and commercial drive tests.
- Technology roadmap for ICT extends beyond 3G technologies to MIMO-OFDM.