Physical Layer ARQ: Discussion Items

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Source: Joe Kwak
Interdigital Communications
482 Degas
Bolingbrook, IL 60440

Voice: +1-630-739-4327
Fax: +1-630-739-4327
E-mail: joekwak@mcs.net

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Base Document:
Purpose: This presentation presents the concept for the proposed new Physical ARQ (PARQ) feature and lists relevant discussion items to assist the working group in deciding how to resolve the PARQ comments.

Physical Layer ARQ: Discussion Items

12 November 2001

Joe Kwak

Interdigital Communications

Presentation Outline

1. **Recap Physical Layer ARQ (PARQ) Proposal**
2. **MAC ARQ and PARQ Distinct Features and Benefits**
3. **MAC/PHY Interface for PARQ**
4. **3GPP Standards: PARQ in W-CDMA**
5. **PARQ Performance Benefits**
6. **Summary for Group Decision**

1. Recap Physical Layer ARQ (PARQ) Proposal

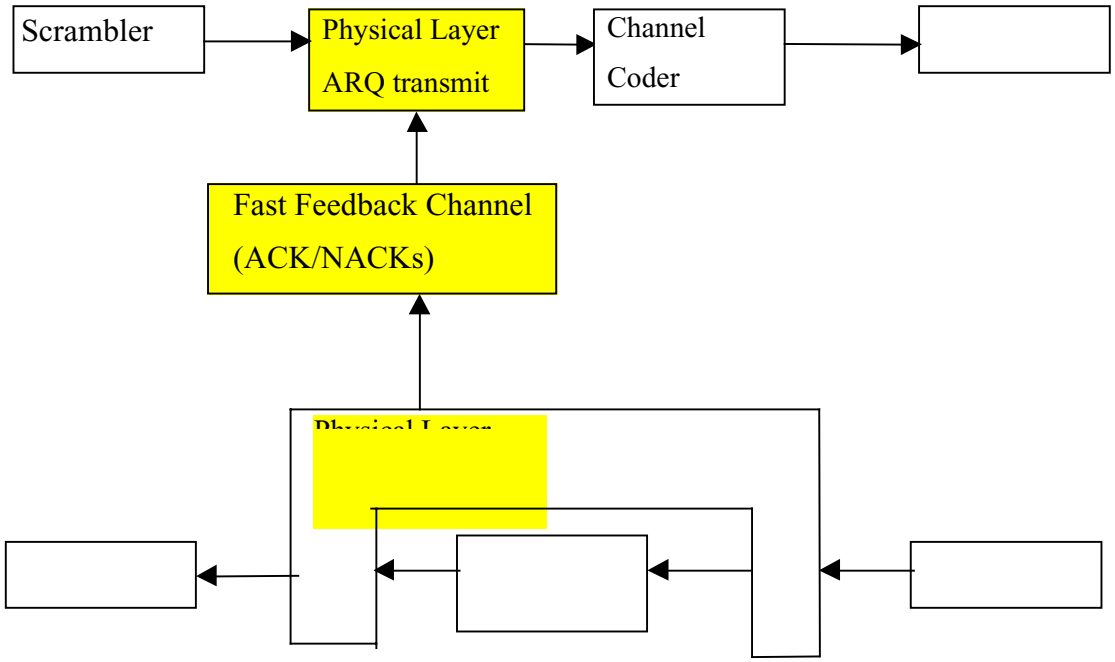
BACKGROUND:

- **A Physical Layer ARQ (PARQ) approach exists which can significantly increase link performance.**
- **ETSI's 3GPP group is working on a modification to WCDMA which will use a fast feedback Hybrid ARQ scheme to improve performance for High Speed Downlink Packet Access (HSDPA) applications.**
- **This scheme may also be used as a physical layer feature in 802.16ab for BFWA applications.**
- **Comments to include functional requirements for PARQ as option in DL have been submitted for consideration in section 8.3 of 802.16.ab-01/01r2.**
- **Resolution of PARQ comments to be discussed and decided at this November meeting.**

Definition of Physical Layer ARQ (PARQ)

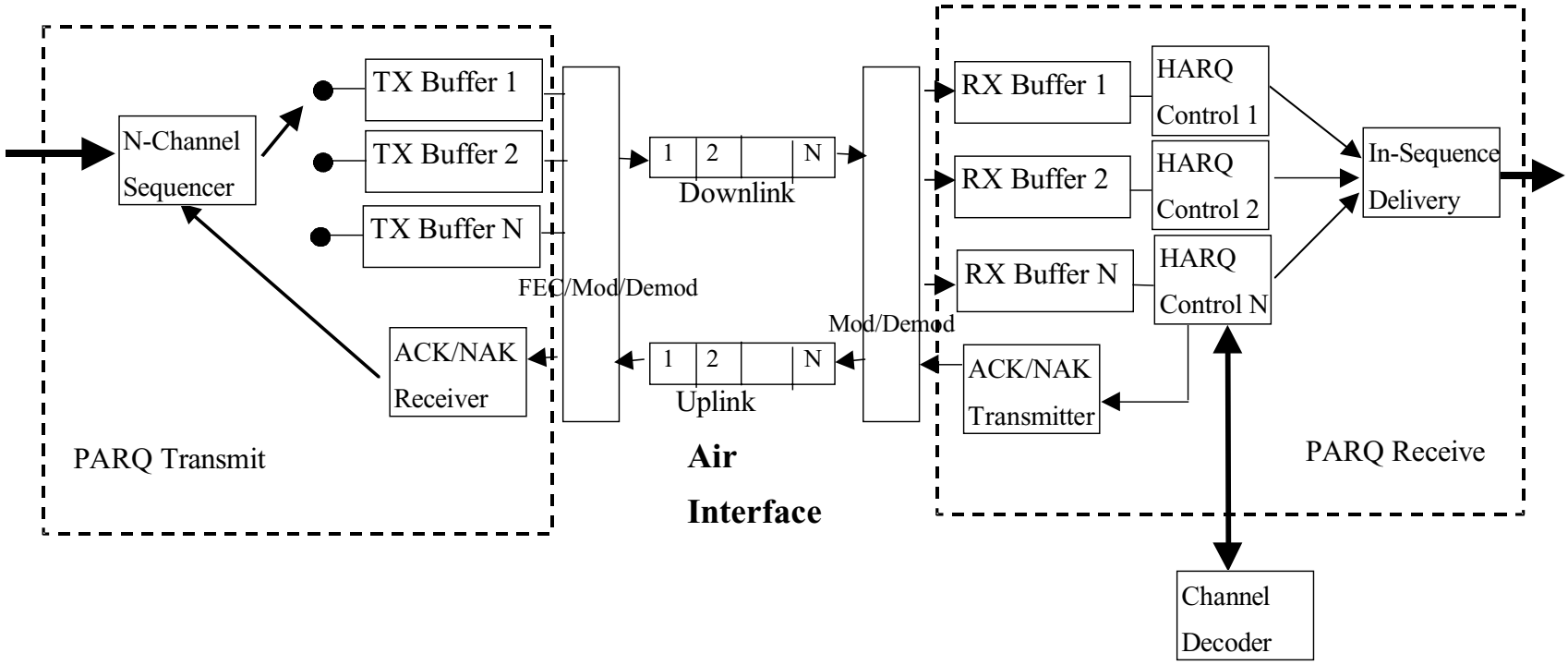
- **ARQ function embedded in the downlink Physical Layer, between data scrambling and FEC on TX side and around the FEC decoder on the RX side.**
- **At RX side, uses Hybrid ARQ combining of retransmission with original errored transmission to improve performance**
- **Uses N-channel architecture with Stop-and-Wait protocol with a small TX and RX buffer for each channel**
- **N-channel implementation eliminates the idle transmit periods (stalls) typical of Stop-and-Wait protocols.**
- **Requires low-latency uplink signaling channel for ARQ feedback**
- **Proposed as option for Downstream only, also applicable for Upstream**
- **PARQ features, functions and architecture further described in 80216abc-01_27.pdf which was presented at last meeting.**

Modified Figure 164, page 106

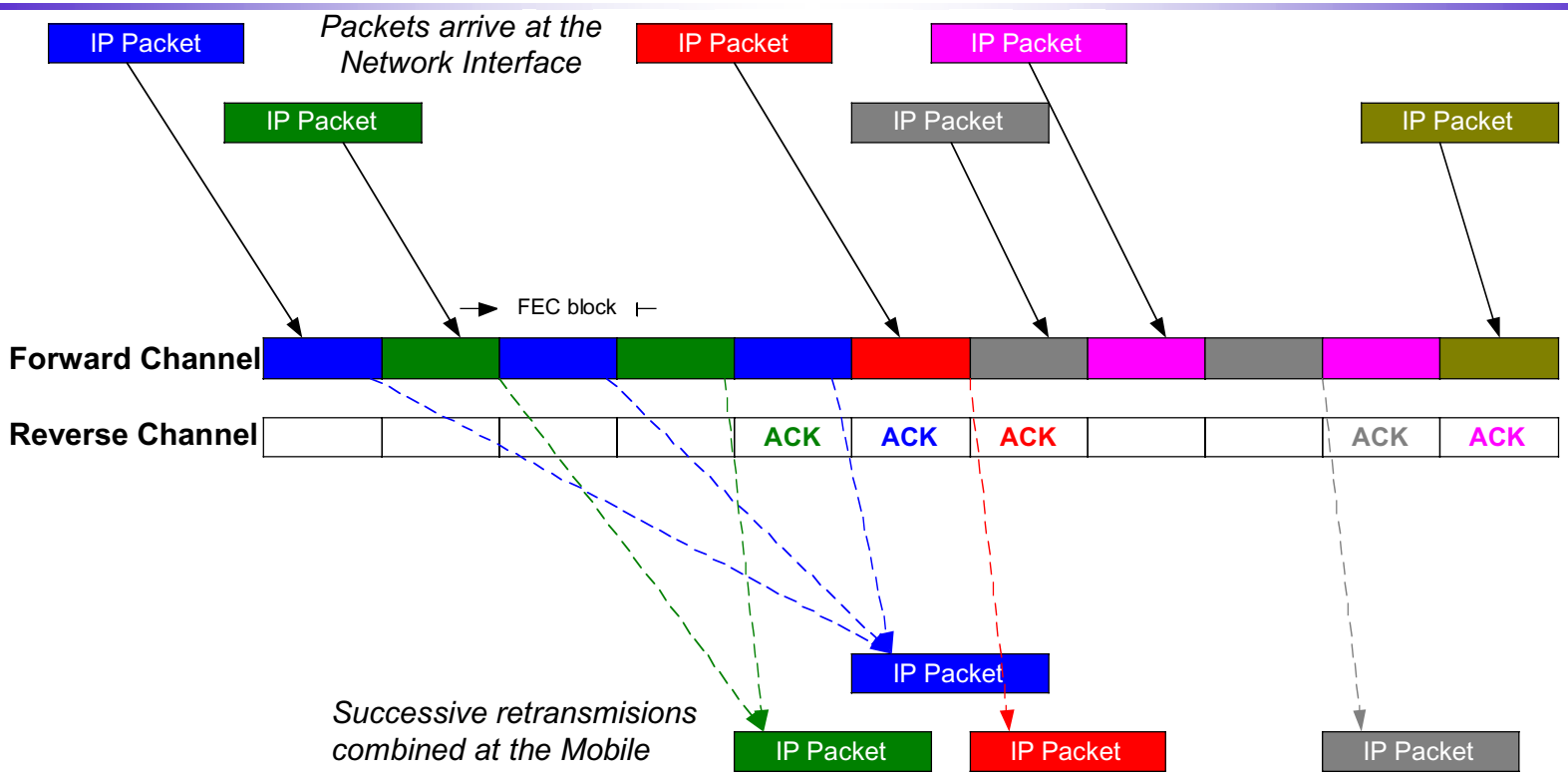


¥ **Figure 164a--Generic PHY block diagram**

Draft new Figure xx, page 123



Dual Channel Adaptive Hybrid ARQ Example



- **Dual Channel Stop-and-Wait ARQ *enables* Adaptive Hybrid ARQ (HARQ)**
  - **The dual channels avoid stalls normally associated with stop-and-wait by providing a one frame delay to communicate ACKs**
  - **Memory and control overhead costs of HARQ significantly reduced**
  - **Transmit FEC block buffer released within 5 FEC blocks after two retransmissions**
  - **Nmax parameter used to limit number of retransmissions and end-to-end transmission delay**

Key Benefits of PARQ feature

- **Significant improvement (2-7 db lower SNR) in PHY layer by operating at much higher BLERs (5-40% BLER) with smaller blocks**
- **PARQ trades delay and some capacity for reduced Eb/No operating point without compromising end-to-end error rate.**
- **Improved performance using advanced Hybrid ARQ techniques: Chase combining, or Turbo coding with Incremental Redundancy**
- **Achieves PARQ benefits without MAC modifications: Physical layer feature independent of MAC layer ARQ.**
- **PARQ ACK/NACK statistics can provide new input to AMC decision algorithm**
- **Use of fast feedback ACK/NACKs for AMC decision permits lower latency channel adaptation than is possible using only MAC or higher layer QOS feedback.**

PARQ Unique Features

- **PARQ is Adaptive**
  - **Adapts to instantaneous link quality**
  - **Adds redundancy only when needed**
  - **Receiver saves failed transmission attempts to help future decoding**
  - **Every transmission helps, increasing the packet success probability**
- **PARQ uses Hybrid ARQ combining technique**
  - **Method 1 : Code Combining (Chase, 1985)**
    - Packet contains info and redundancy
    - Retries are identical to first packet attempt
    - Max-ratio combining of symbols
  - **Method 2 : Turbo coding + Code Combining**
    - Packet contains info and redundancy
    - Retries contain additional redundancy
    - More complex than Method 1, but offers potential throughput gain

Impact of PARQ on current 802.16ab Draft Standard

- **PHY agnostic, may work with either SC-FDE or OFDM schemes**
- **Requires design of new upstream Fast Feedback Channel (FFC)**
- **May be used in both FDD and TDD modes, though FFC for TDD is more complex**
- **Proposed in downstream, but also possible for upstream**
- **Proposed as optional feature with configurable connection parameters in MAC layer, NOT assumed to be required for all SS's or for all connections (CIDs) for a given SS.**

PARQ for Uplink as well as Downlink

- **PARQ can provide increased capacity and increased link range for both uplink and downlink connections.**
- **The specification comments submitted for resolution at this meeting indicate the addition of PARQ as an optional feature in the Downlink only.**
- **If the group agrees, the comments may be revised to include PARQ as an option in both the Uplink and Downlink.**

- **This will not constrain any existing system designs which do not include PARQ, yet will permit newer systems to take advantage of the advanced PARQ feature.**

2. PARQ and MAC ARQ: Distinct Features and Benefits

- **PARQ is primarily a feature which enhances the effectiveness of FEC decoding by soft combining immediate retransmissions of FEC blocks sent at high BLER operating points. This permits operation at lower SNR values.**

- **PARQ is a Physical layer function which controls the FEC encoding and FEC decoding functions using an embedded Physical Layer Fast Feedback Channel (FFC) for control signaling.**

- **MAC ARQ is an error control feature which retransmits errored MAC PDUs in a flexible fashion to achieve error free data delivery. MAC ARQ retransmissions may occur long after original transmission and the retransmission may be segmented and piggybacked on other MAC PDUs using the granularity of the defined ARQ block size. This provides good transmit time diversity for retransmissions.**

- **PARQ alone cannot provide error free delivery of data. At times PARQ FEC blocks will be retransmitted the maximum number of times without success.**

CAN MAC ARQ provide PARQ-like functions? Yes, BUT….

- **MAC ARQ could be enhanced to provide functions like PARQ:**
  - **Rx MAC CRC would control PHY FEC decode and soft buffers, new controls needed.**
  - **MAC PDU size ==>single ARQ block = single FEC block (=< 239 bytes)**
  - **Sufficient feedback bandwidth needed for frequent, low-latency selective ack ARQ_feedback_Ies. Efficient cumulative ACK not possible at high BLERs**
  - **MAC header needs PDU# for new PDU NACK message for high BLER operation**
  - **OR Sufficient soft buffer needed to accommodate selective ACK of up to 64 MAC PDUs**
- **But if MAC ARQ is modified to operate in this way for immediate FEC block retransmissions, WHAT OTHER FUNCTION will provide error free delivery with time delay transmit diversity?**

PARQ and MAC ARQ Serve Different Purposes

Service / Condition	Link provides less than max data rate	Link provides max data rate
Error free service	PARQ enabled MAC ARQ enabled	PARQ disabled MAC ARQ enabled
Error tolerant service	PARQ enabled MAC ARQ disabled	PARQ disabled MAC ARQ disabled

- **PARQ enhances FEC and thus Radio Link Margin.**
- **MAC ARQ provides acknowledged-mode error free data delivery.**
- **Both features are needed; a single ARQ mechanism is not adequate.**

3. MAC/PHY Interface for PARQ

- **Assumptions for PHY channel comparison with/without PARQ:**
  - **MAC connection uses 2.4Kbyte PDUs with .1% required BLER from PHY channel, with 100 BW units per DL MAP required throughput.**
  - **Service Flow QOS requires error-free delivery.**
  - **MAC provides ARQ to correct the erred PDUs by SDU retransmission.**

Channel Parameter	PHY without PARQ	PHY with PARQ
BLER on MAC SDUs	<.1%	<.1%
Error Check Block	MAC PDU (2.4 Kbyte)	FEC block (239 byte)
Retrans Block	MAC PDU (2.4 Kbyte)	FEC block (239 byte)
Retrans Blocks/SDU	1	10
Retrans Block BLER	<.1%	<30%
PHY SNR	20 db	14db
BW units allocated	100	130
SDU Thruput delay	X (fixed)	X+Tparqmax/-0 (variable)

MAC PDU Scheduling

- **Scheduling of PHY burst transmissions by MAC must allow for the PARQ retransmissions of erred FEC blocks.**
- **The TXVECTOR in the PHY_TXSTART primitive provides PHY with the TX burst parameters and burst length defining the MAXIMUM data capacity of the TX burst.**
- **MAC may schedule MAC PDUs whose aggregate capacity is equal to the maximum capacity of the TX burst.**
- **PHY will sequentially provide TXSTATUS to MAC for each scheduled MAC PDU after each MAC PDU has been transmitted.**
- **At the end of the TX burst, PHY will indicate to MAC an unsuccessful transmission of any MAC PDU which was only partially transmitted.**
- **MAC would schedule smaller PDUs at end of burst to minimize truncation loss.**
- **In the prior example, MAC would schedule 130 BW units of MAC PDUs for a given TX burst, but PHY would indicate truncation after transmitting about 100 BW units.**

Connection Parameters for PARQ

- **If a Service Flow is configured to use PARQ then the MAC primitives for Connection creation/management will contain PARQ parameters.**

- **PARQ parameters include:**
  - **Nsaw, number of Stop -And-Wait channels to implement for this connection. Dependant on processing and transmission delays at TX and RX end of connection.**
  - **Ntxmax, maximum number of retransmissions of an FEC block before discard.**
  - **Fast Feedback Channel (FFC) parameters:**
    - CDMA code(s) for ACK/NACK feedback
    - Feedback burst timing parameters for synchronous ACK/NACK transmission. This will be a set of parameters to cover all possible AMC burst profiles for this connection.

4. 3GPP Standards: PARQ in W-CDMA

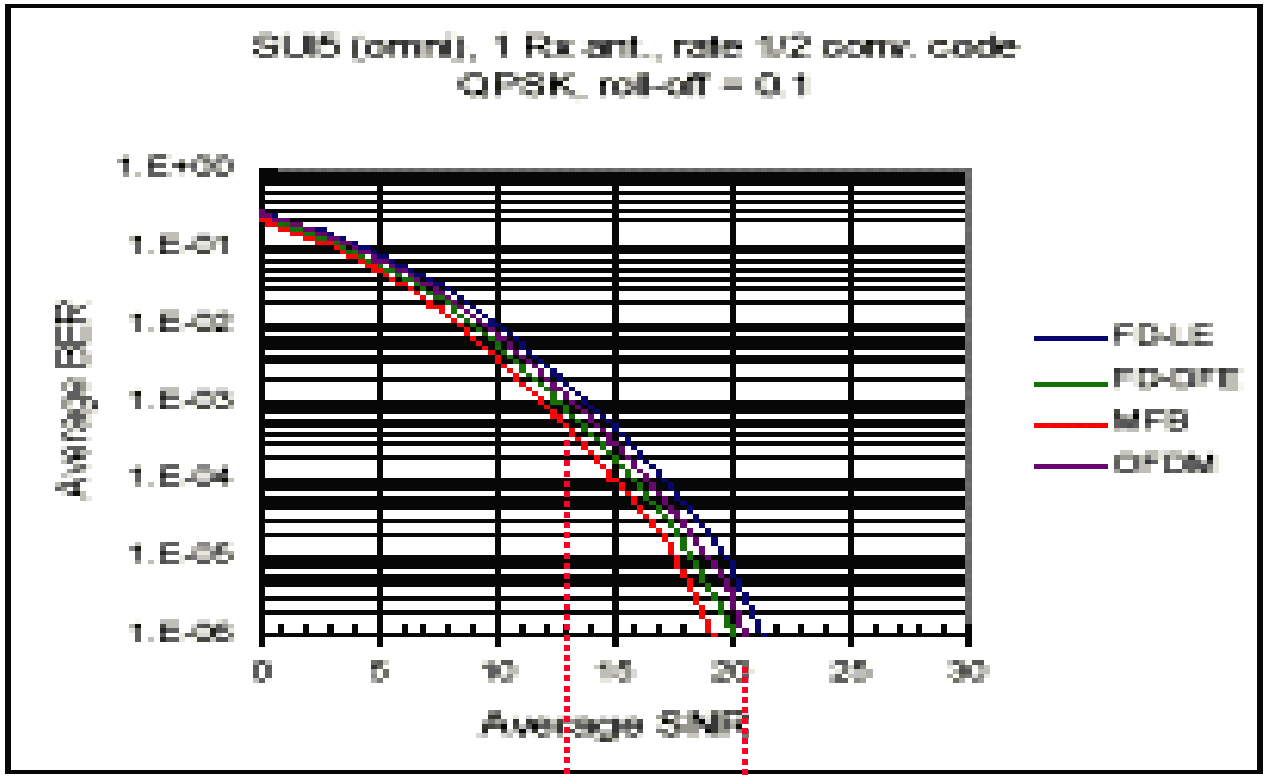
- **ETSI's 3GPP continues to develop the W-CDMA standard for 3G mobile systems.**
- **3GPP has been studying PARQ feasibility, benefits and implementation issues over the past 20 months.**
- **3GPP has studied the complexity and the benefits of using Chase combining and Incremental Redundancy with Turbo codes on short TX blocks operated at 10-60% BLER with fast Physical Layer ARQ.**
- **3GPP has decided to incorporate PARQ as a part of the new High Speed Downlink Packet Access (HSDPA) feature.**
- **80216abc-01/57 contains the Feasibility Study Report (TR25.848) which includes the PARQ feature.**

5. PARQ Performance Benefits

- **At the last meeting an example of PARQ gain was presented and showed an approximate 7 db SNR gain.**
- **These PARQ SNR vs BER gains are composed of:**
  - **Gain due to decreased block sze (0-5db)**
  - **Gain due to increased BLER operating point (0-5 db)**
  - **Gain due to soft combining of multiple transmissions (1-4 db)**
  - **Loss due to increased capacity for retransmissions (0.1-1.0 db)**
- **Overall resulting gains for PARQ are expected to be in the 2-7db range.**

PARQ SNR Gain Example

Simulation Results from 802163p-01_31r2.pdf



Improvement using PHY ARQ = 7 dB

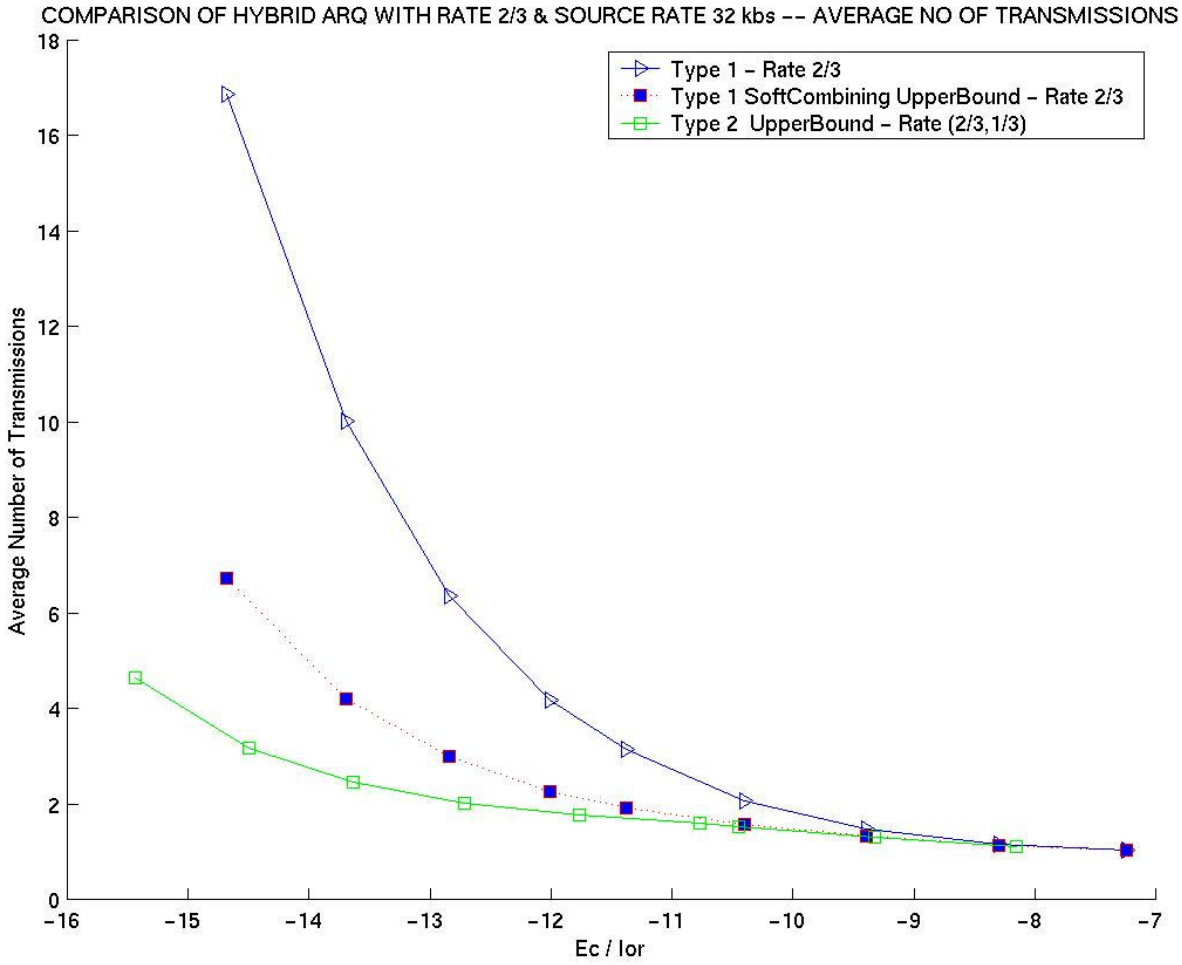
PHY ARQ operating point:
BER = 10-3 (10% BLER, 100 bit block)

MAC ARQ operating point:
BER = 10-6 (.1% BLER, 1000 bit block)

PARQ Soft Buffer Combining Simulations

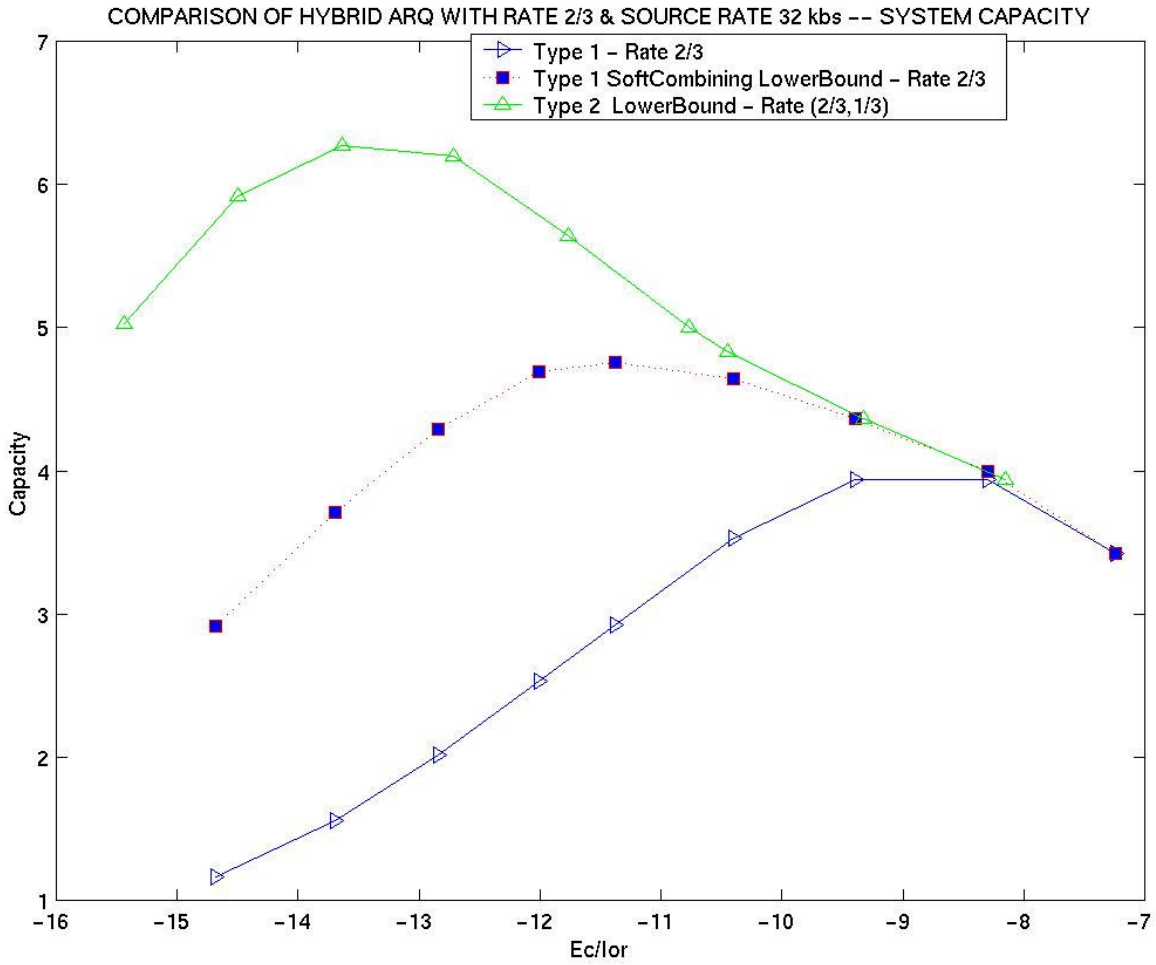
- **At last meeting several companies expressed interest in collaborating on simulations to verify the PARQ gains due to Chase combining with RS/CC codes and Incremental Redundancy (IR) combining with TPC.**
- **Good intentions were not afforded adequate time and resources to complete simulations tailored to the FEC codes chosen by 802.16ab.**
- **Nokia, Lucent, Samsung, and Wiscom all provided simulation results in support of 3GPPs HSDPA feasibility study.**
- **Some representative simulation results are provided and referenced here.**

Nokia Simulations [TSGR1#21(01)0869]



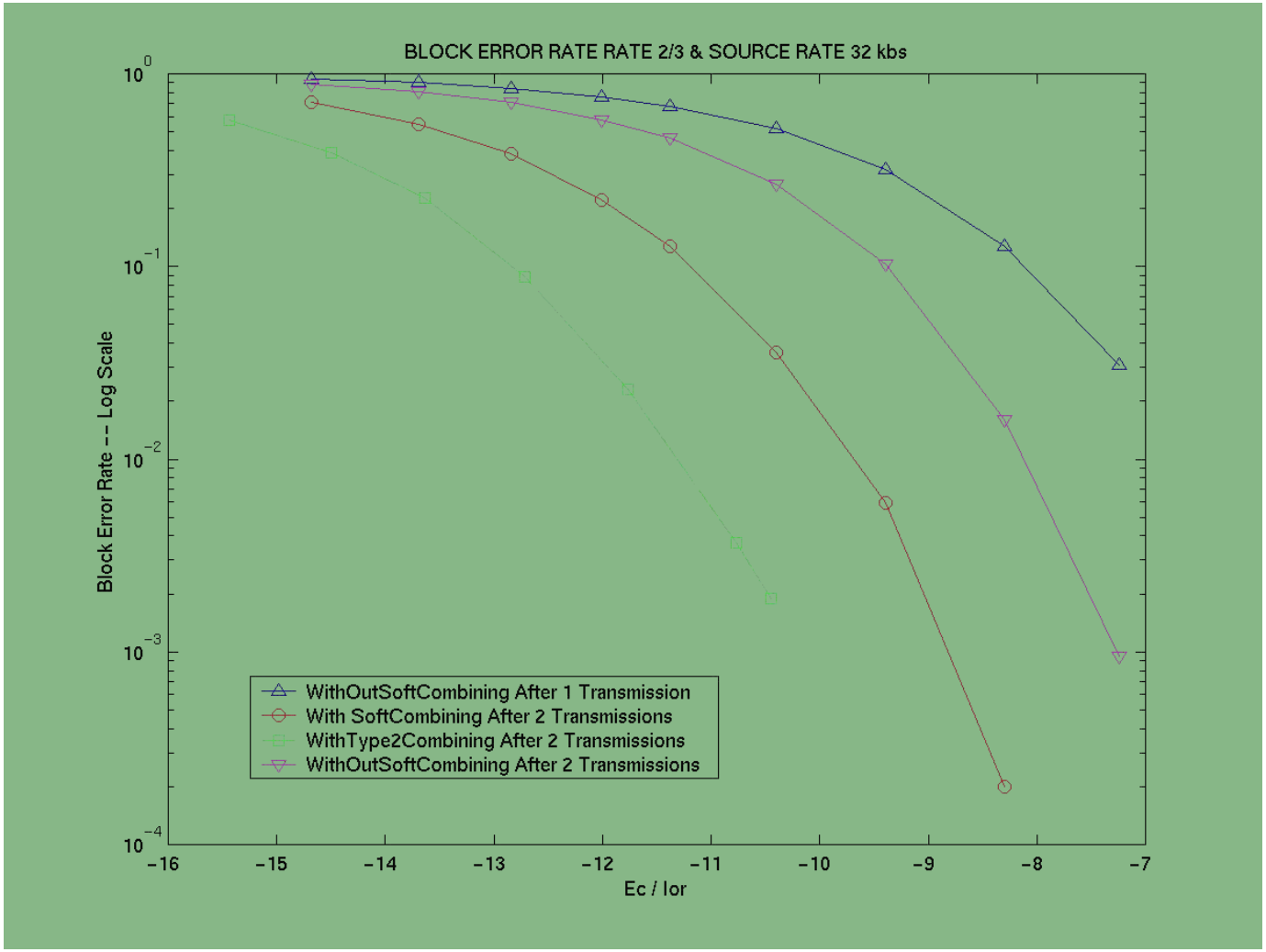
¥ **Average number of Retransmissions**

Nokia Simulations [TSGR1#21(01)0869]



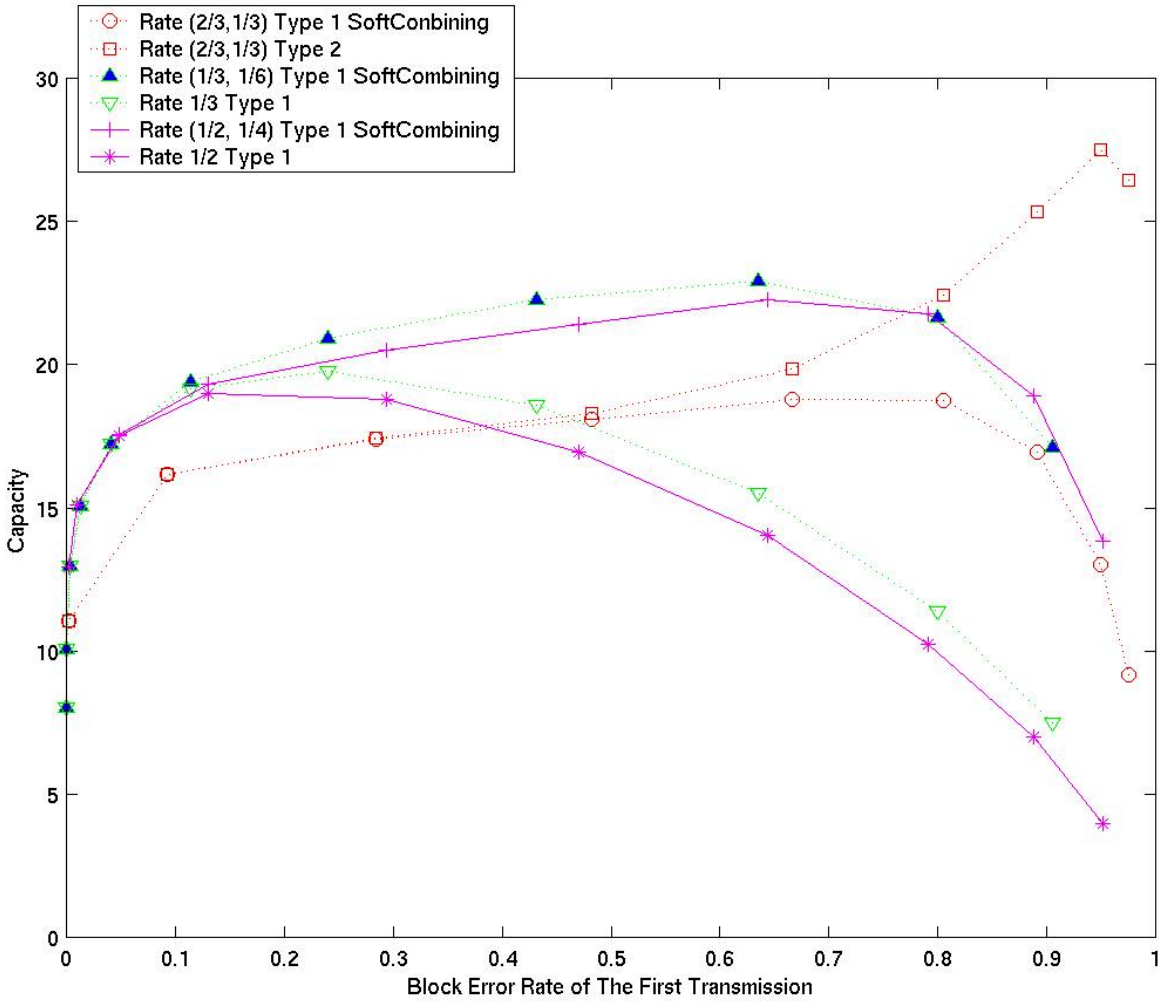
¥ **Cell Capacity vs. Ec/Ior**

Nokia Simulations [TSGR1#21(01)0869]



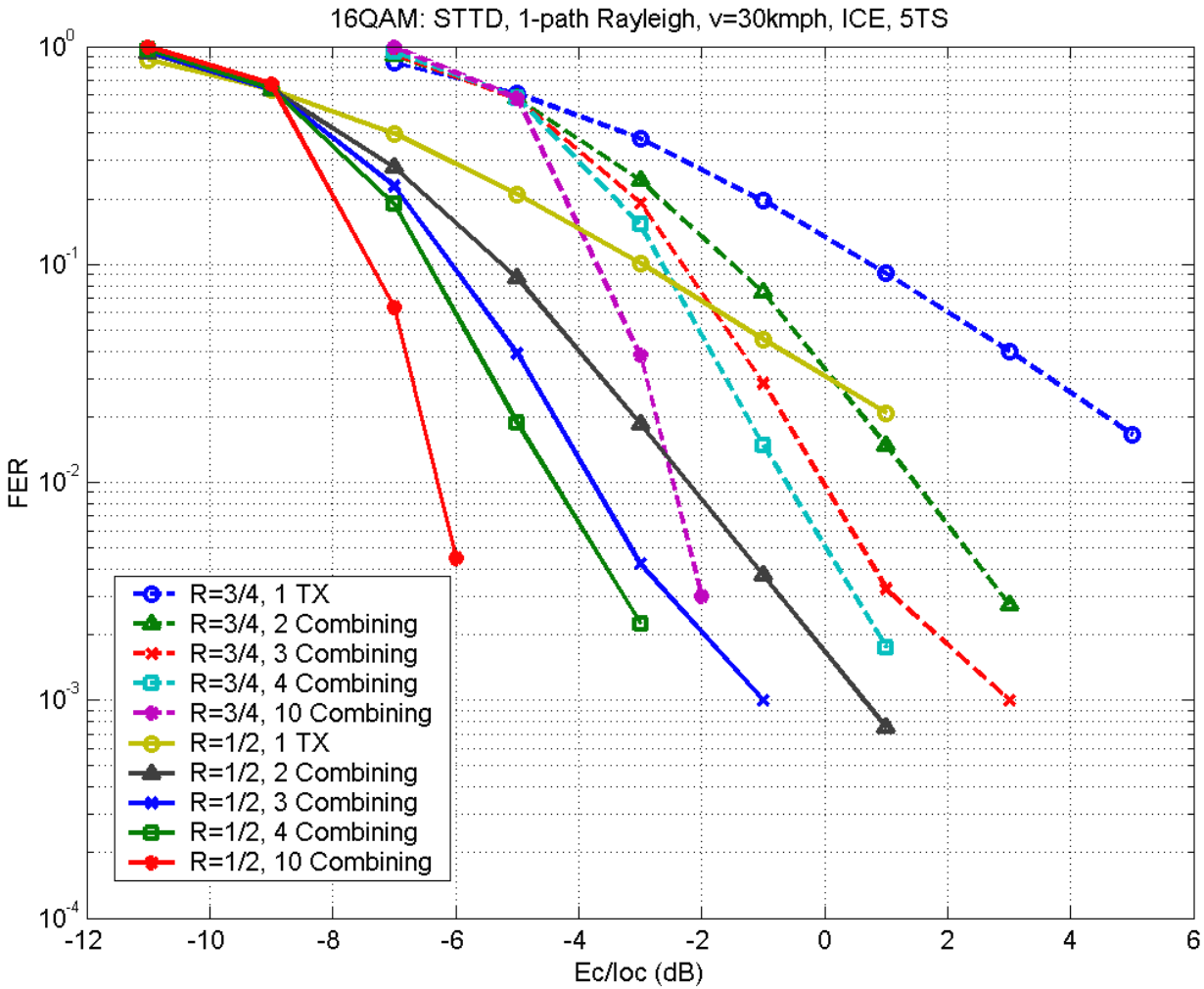
¥ **BLER vs. Ec/Ior Performance**

Nokia Simulations [TSGR1#21(01)0869]



¥ **Cell Capacity vs. BLER**

Wiscom Simulations [TSGR1#20 (01)0538]



¥ FER versus Ec/Ioc for 16QAM. STTD on, 1-path Rayleigh channel, speed = 30Kmph, ideal channel estimation, frame length=3.33ms, HARQ with Chase Combining

6. Summary for Group Decision

- **PARQ is an advanced feature which enhances FEC to provide significant benefits.**
- **PARQ is distinct from MAC ARQ:**
  - **PARQ uses immediate retransmissions of short FEC blocks at high BLER with soft buffer recombining.**
  - **MAC ARQ uses delayed retransmission of longer MAC PDUs to provide time diversity for error-free delivery at low BLER.**
- **Both MAC ARQ and PARQ are needed to augment the set of data communications capabilities in 80216ab-01/01r2 specification.**
- **To serve the expanding needs of future BFWA systems, it is prudent to add PARQ as a supported optional feature.**