The powerful combined effect of Forward Error Correction and Automatic Repeat reQuest to improve the reliability in the wireless communications

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Abstract— **In this paper, we focus on efficient method for improving the reliability of data retransmission in real operational wireless communications. We analyze the effects of ACK (Acknowledge) and FEC (Forward Error Correction) on practical transmission performance of different message sizes. We propose a novel idea which allows quantifying and qualifying the reliability improvement in the network remote performance by exploiting Payload bitrate and forwarding time versus average message size with/without ACK/FEC respectively.**

Keywords— Networks wireless; ACK; FEC; Remote wireless communications; Router.

I. INTRODUCTION

WIRELESS Network communications is a rapidly growing domain of the communications industry, with the potential to assure high-speed high-quality information exchange between routers remote management and portable devices located wherever in the world [1].

In router mode, the IP address of either the Radio or Ethernet interface in the remote unit can be used for such remote management. IP routing between source (IP of ETH interface in Local Router) and destination IP (either Radio or ETH interface in Remote Router) must be excited.

The router network performance is affected by several factors [2], including the data transfer rate of the node, the nature of the transmission medium, the physical distance between the nodes, the number of nodes in the path, the speed between intermediate nodes and source node functions, the ACK, the modulation mode and the FEC.

Transmissions and receptions are accomplished by an antenna system and can be Directional (Point-to-point focused using high frequencies) or Omnidirectional (Waves propagating in all directions using lower frequencies).

The missions of forwarding time and payload bitrate measurement are the collection and preprocessing of the information from all Router nodes in the network operating.

FEC is a technology that not only can control errors in data transmission and detect an error on the received signal, but can also add enough redundancy of the data so that it can correct the erroneous bit. It can correct two wrong bits, since redundancy increases the data-rate of the packet.

Narrowband Router transceivers transmit and receive data over a very narrow bandwidth (a few kHz) in the licensed privy radio frequency (RF) spectrums [3]. It uses FEC algorithms in order to furnish protection against noise errors as in the case of a DTT (Digital Terrestrial Television) broadcasting system [4].

In fact, we will add, in our work, a type of FEC to the wireless network in order to minimize the number of errors caused by the various problems such as the problems of the hidden nodes and power reduction.

ACK is a transmission control character used to indicate that a transmitted message was received uncorrupted or without errors or that the receiving station is ready to accept transmissions. The receiver sends the code to the sender to indicate that the transmission has been accepted

Three approaches can be used to cope with data transmission errors:

1) Automatic Repeat reQuest (ARQ): Error detection
2) FEC: Error detection and correction.
3) Hybrid ARQ (ARQ+FEC): Error detection and correction [5].

In general, wire-line communications (more reliable) adopts ARQ [6], [7] scheme, while wireless communications (relatively less reliable) adopts FEC scheme.

To improve the reliability of data transmission, which is an essential problem in wireless communications, ARQ schemes were introduced. However these ARQ schemes suffer from a reduction in the throughput. To address the throughput reduction, conventional ARQ schemes were combined with FEC schemes to develop hybrid-ARQ (HARQ) schemes. For improving the reliability of data

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transmission, HARQ schemes are included in the present wireless network like (WiMAX) [8] and 3GPP-LTE [9].

HARQ systems use ACK and negative acknowledgement (NACK) signal feedback to determine whether retransmission of a data packet is required or not.

The performance of wireless network is measured, in general, by several parameters such as BER versus S/N, RTT/Parquet length [10]…, but in our case we apply a simple and efficient method by using the Payload bitrate / forwarding time versus average message size with/without ACK/FEC respectively.

This paper is organized into six sections including introduction. Section II gives the ACK utilization principle of our experiment. Section III gives an overview of FEC. Section IV describes the experimental setup. In Section V results of practical measures in real time hardware are presented. Conclusions are given in Section VI.

II. ARQ: Error Detection And ACK Messages

ACK is a message usually sent by a network unit to another to acknowledge receipt of an event (reception of a message, for example), using the very short service packet (ACK), in order to indicate that it has received the packet successfully. If ACK is not received, Router will retransmit the packet according its setting of Retries.

- When a receiver circuit detects errors in a block of data, it requests that the block be retransmitted. The receiver sends a feedback to the transmitter: Error is detected (NACK: Not-Acknowledgement) in the received packet, then retransmit that data block, or if no errors detected (ACK: Acknowledgement), don't resend.
- The transmitter retransmits the previously sent packet if it receives a NACK.
- Uses extra/redundant bits merely for error detection.
- Full-duplex (two-way) connection between the Transmitter and the Receiver.
- Result: Constant reliability, but varying data rate throughput due to retransmit.

Note: The acknowledgement/retransmission scheme is an embedded part of the Radio protocol and works independently of any retries at higher protocol levels (e.g. TCP or user application protocol).

1) *Case of a transmission without errors.*

Consider the exchange represented by the temporal diagram in Figure 1, we distinguish the following steps:

- Transmission of the data block, where **U** represents the payload and **G** the protocols management data;
- A dead time during which the transmitter waits for the acknowledgment that corresponds to transit time round trip on the support and the time processing data received by the receiver. This time, generally referred to as the time of crossing of the equipment, noted RTT (round trip time) [11] equivalent to the transmission of (D · RTT) bits where D is the nominal flow of the system;
- Finally receiving the acknowledgment of K bits
- The time between transmission of the first bit of the block N and the first bit of the next block (N + 1) is called latency and noted Ta.

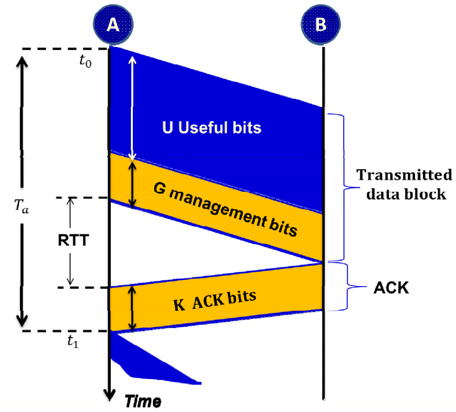

Fig.1. Efficiency of basic mode

To estabish the efficiency of protocol in an error-free transmission,we recall that the efficiency of a protocol (E_0) is the ratio between the number of useful bits transmitted (U) to the total number of bits transmitted or that could have been transmitted (N).

$$E_0 = U / N \tag{1}$$

The number of bits that could be transmitted between t_0 and t_1 (Ta) can be expressed by the relation:

$$N = U + G + K + D \cdot RTT \tag{2}$$

Therefore, we can determine the effectiveness of the Protocol in the case where no error occurs:

$$S = G + K + D \cdot RTT \tag{3}$$

Where D. RTT, G and K are respectively the number of bits representative of the time crossing equipment, the management bit (control, address ...) and the acknowledge bit.

Substituting (2) and (3) in (1), the Protocol efficiency error-free will be:

$$E_0 = U/N = U/(U + S)$$

2) *Case of a transmission with errors*

If t_e (error rate) is the probability for that a bit transmitted is wrong, (1-t_e) is the probability for that a bit is correctly transmitted. If the transmission relates to N bits, the probability for those N bits are properly transmitted is:

$$p = (1 - t_e)^N \quad \text{with} \quad N = U + G$$

The probability that the ACK either successfully transmitted is:

$$p = (1 - t_e)^K$$

The probability for a block to be correctly transmitted can be defined as follow:

$$p' = (1 - t_e)^N.(1 - t_e)^K$$

The efficiency of the protocol with error (E_{er}) is then:

$$E_{er} = U \cdot (1 - t_e)^N.(1 - t_e)^K /(U + S)$$

We can therefore assume that efficiency in case of fault is compared to the error and we can write:

$$E_{er} = U/(U + S).(1 - t_e)^N.(1 - t_e)^K$$

Or $$E_{er} = E_0.(1 - t_e)^N.(1 - t_e)^K = E_0.(1 - t_e)^{N+K}$$

Since K≪ N, we can therefore admit that the efficiency in case of fault is compared without error:

$$E_{er} = E_0.(1 - t_e)^N$$

III. Channel FEC Coding Techniques

In telecommunication, FEC is a technique used for controlling errors in data transmission over unreliable or noisy communication channels. It is a very effective method to minimize radio channel impairments. Basically the sender encodes the message in a redundant way by using an error-correcting code (ECC). Therefore the sender inserts some redundant data into its messages. This redundancy allows the receiver to detect and correct errors (to some extent). The improvement comes at the expense of the user data rate.

The role of the FEC subsystem is to reduce the frequency of retransmissions by correcting the errors in the received packets. This increases the throughput performance.

FEC coding techniques are classified as either block codes or convolutional codes [12]. The classification depends on the presence or absence of memory.

The lower the FEC ratio promotes the better capability of error correction and the lower user data rate. Where the user data rate is the product of the modulation rate and the FEC ratio.

A. Benefits /Cost of FEC For a Digital Communication System

- FEC can offer an improvement of 3dB to 5dB in system performance.
- Reduce the required frequency bandwidth
- Increase data throughput
- Reduce antenna size.
- Increase range/distance or reduce the transmitter's RF power.
- Access by more users to the same radio frequency in a multi-access wireless communication system can be ensured by the use of error control technique.

But, it must be noted that the FEC could promote an increase bit overhead (line rate), time delay, and processing complexity Channel FEC Coding Techniques Digital Communication Systems.

It is noteworthy that the ARQ and FEC may be combined, such as minor errors are corrected without retransmission, and major errors are corrected via a request for retransmission (HARQ). A HARQ system consists of an FEC subsystem contained in an ARQ system.

IV. Experimental Setup

We consider average hop count to the remote sites. One remote station directly connected to the center (one radio hop) and one remote station.

Each Router unit's node in Wireless Network (as showed in figure 1) is defined for a selected payload bitrate and a One-hop forwarding versus average message size by configuring them, with source and destination addresses, using the protocol SCADA(Supervisory Control And Data Acquisition) software.

In our practical application, the topology showed in Fig. 1 is well-respected. Router units module configured as a source *A* sends packets to destination *B* and come back to *A*.

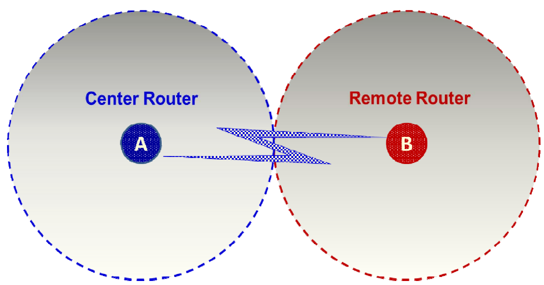

Fig.2. Wireless router network topology

Each frame transmitted on Radio channel from this router has to be acknowledged by the receiving router, using the very short service packet (ACK), in order to indicate that it has received the packet successfully. If ACK is not received, router will retransmit the packet according its setting of Retries.

Note: The acknowledgement/retransmission scheme is an embedded part of the Radio protocol and works independently of any retries at higher protocol levels (e.g. TCP or user application protocol).

When ACK is not enabled, there is no requirement to receive ACK from the receiving router. i.e. the packet is transmitted only once and it is not repeated.

The aim of this experiment is to measure the Payload bitrate/forwarding time versus average message size to gain a sense as how does the with/without ACK/FEC respectively affect the performance of the modules communicating over SCADA (supervisory control and data acquisition) protocol.

1) Selection of various network conditions.

The equipments, including computer software used, are:

- Two RipEX units (routers use the same band VHF /UHF (band IV and V) which are characterized by the SNMP (Simple Network Management Protocol) management that will support the base MIB (Management Information Base) .

- VHF/UHF bands 350 MHz this band is somewhere between 160 and 450 MHz, destined to broadcasters have highly advantageous propagation characteristics.

- We can use the omnidirectional antenna KA160.3 which is designed for base radio stations. The antenna used in our application has an omnidirectional radiation pattern with the gain of 3 dB and is adapted for the top-mounting.

- The values received at the level of each site vary between 38 and 70 dBμV what is recommended to plug user for correct operation of household appliances for the bands III, IV and V.

- The output power of each router varies between 0.1 and 10 watts (default=10watts).

- We are in the condition where a signal travels over the air directly from a wireless transmitter to a wireless receiver without passing an obstruction Line-of-sight (LOS). For our case router nodes are kept at distances 2 km.

2) Selection of various network conditions.

Various measurements are effectuated, as a function to different values of message size and ACK/FEC, each Router units module may support up to 1500 bytes (User data size without any headers (IP, TCP, UDP …) of RF payload. Therefore, to avoid reception overcharge with it, we should considered, in this article, that the Average message size is to use data size without any headers (IP, TCP, UDP …).

As the Payload bitrate and forwarding time measurement are affected by different parameters of the wireless network [2] the various conditions have to be required on the selection of wireless network. These conditions are mentioned in table I.

TABLE I. ROUTER SETTINGS

Condition Imposed on selected network.	Condition Chosen or demanded
FEC	ON/ Off
ACK	ON/OFF
Interface speed	ETH TCP/IP
The nature of the transmission medium.	Wireless
Channel spacing [kHz]	50
Modulation rate [kbps]	166.67/16DEQAM

V. RESULTS OF PRACTICAL MEASUREMENTS.

A. Payload bitrate Measurement at different message sizes

The goal of this experiment is to measure the Payload bitrate, in kbps, of the router units remote as a function of the message size then we make the comparison with the simulation results.

Since RipEX uses customized IP packet on the Radio channel, payload bitrate includes 28 bytes of IP packet overhead –20B IP header and 8B UDP header. This measurement assumes using the UDP as the Layer 4 protocol. If we are using TCP, the resulting bitrate would be lower due to a higher TCP overhead; we can use our TCP proxy functionality to optimize the communication

The results allow gaining, in a manner simpler and more efficient, a sense as how does the Payload bitrate affect the latency of the router units communication protocol.

Various measurements are effectuated, as a function of different values of variable message size and without FEC/ACK or with FEC/ACK respectively. Each RipEX units module may support up to 1500 bytes (User data size without any headers (IP, TCP, UDP …) of RF payload. In this case the shape of payload bitrate curve is shown depending upon message size and ACK/FEC as illustrated in Fig.3 and Fig 4.

1) Measurement results

The scenario is considered in Fig 1: direct transmission between the source A and the destination B using two routers RipEX units. The results measurements are showed in Fig 3.

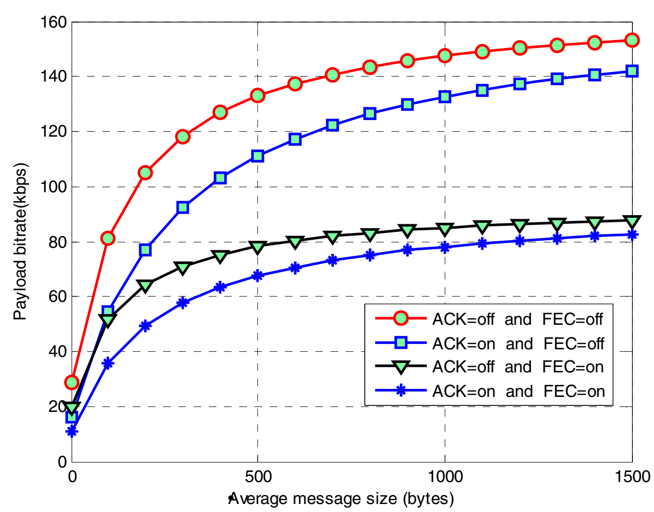

Fig.3. Payload bitrate Measurement at different message sizes

The results in Fig. 3 show that the using different average message sizes (bytes) of the each RipEX units, without FEC/ACK or with FEC/ACK respectively, has a significant effect on payload bitrate (kbps).

Payload bitrate is increased when the message size increase, the introduction of FEC and ACK can also provokes a significant decrease of Payload bitrate.

The introduction of FEC increases Payload bitrate more than the presence of ACK.

For a message value size equal to 1000 bytes we have the following table

TABLE II. PAYLOAD BITRATE

Application of :	Decrease (per cent) of Payload bitrate
ACK	10 %
FEC	42 %
ACK and FEC	47 %

Consequently:

- The introduction of ACK reduces payload bitrate of 10 %.
- The introduction of FEC decreases payload bitrate of 42 %.
- The addition of ACK and FEC allows decreasing payload bitrate of 47 %.

2) Comparison with the simulation results.

To confirm the practical results by simulation we will compare them with the simulation result as illustrated in Fig.4.

We take the case of ACK=on and FEC=on and we have the following results.

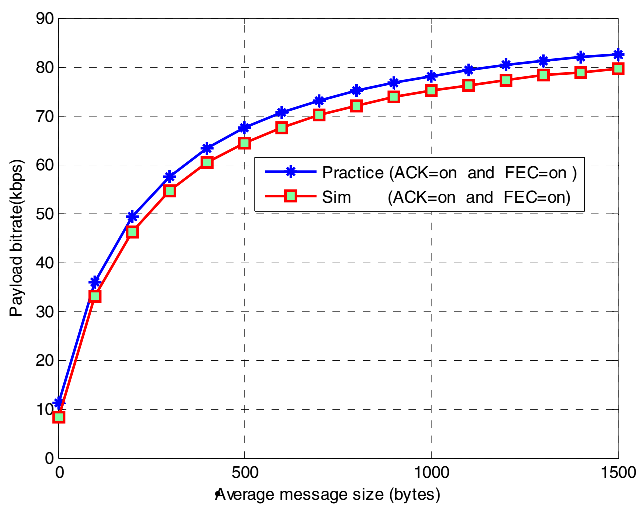

Fig.4. Comparison between the simulation and measurement results.

We find that the practical and simulation results are almost the same.

B. *One-hop forwarding time measurement at different packet length.*

The aim of this experiment is to measure one-hop forwarding time of the RipEX units as a function of the different message sizes and the ACK/FEC to gain a sense as how does the ACK/FEC affect the Payload bitrate of the modules communicating over SCADA protocol.

In our application, the one-hop forwarding time is the average time in milliseconds to transmit a single packet between two RipEX units. Network topology in figure 2 is considered where the message transmitted directly from the Source A to the destination B.

It involves measurement the one-hop forwarding time in milliseconds to transmit an average message size between two Routers units.

1) Measurement results

The results in Figure 5 show, one-hop forwarding time measurement at different message sizes , without FEC/ACK or with FEC/ACK respectively.

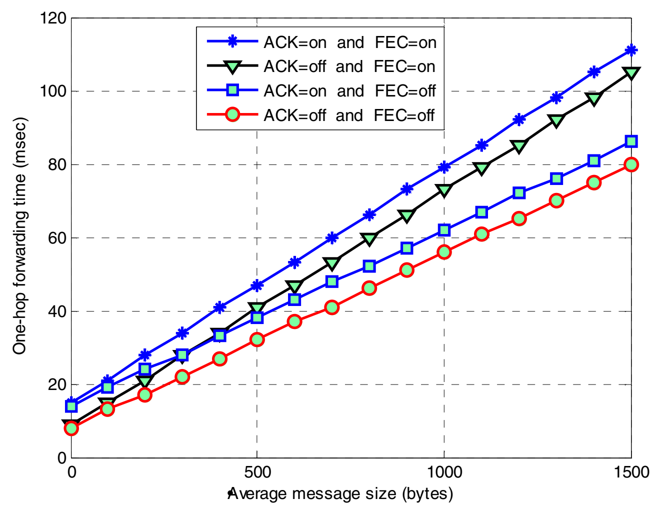

Fig.5. One-hop forwarding time Measurement at different packet length.

The forwarding time is increased when the packet length increase. The introduction of the (FEC = ¾) /ACK can also promote a slight increase in forwarding time.

The introduction of FEC can promote an increase in forwarding time faster than with the presence of ACK (curve ACK=off and FEC =on).

TABLE III. ONE-HOP FORWARDING TIME

Application of :	Increase (per cent) of One-hop forwarding time
ACK	10.72 %
FEC	30.35 %
ACK and FEC	41 %

Consequently:

- The introduction of ACK increases One-hop forwarding time of 10.72 %.
- The introduction of FEC increases One-hop forwarding time of 30.35 %.
- The addition of ACK and FEC allows increasing One-hop forwarding time of 41 %.

2) Comparison with the simulation results.

To confirm the practical results by simulation we will compare them with the simulation result as illustrated in Fig.6.

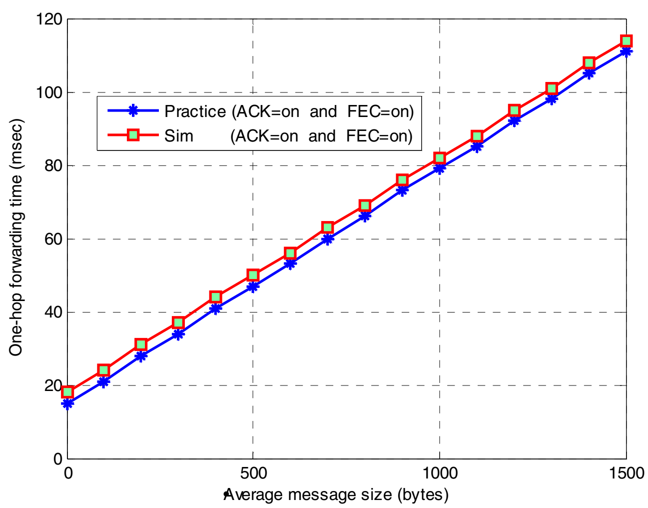

Fig.6. Comparison with the simulation results.

VI. CONCLUSIONS AND FUTURE WORKS.

The resource allocation for the combination ACK /FEC system problem studied in this paper considered as simple efficiency application scenario in which will be the performance metric.

ARQ and FEC may be combined, such that minor errors are corrected without retransmission, and major errors are corrected via a request for retransmission.

When the FEC cannot correct the errors, ARQ takes over and this improves the reliability. Therefore, a proper combination of FEC and ARQ would provide a higher reliability of data retransmission in wireless communications, than the system which uses only FEC and a higher throughput than the system using only ARQ.

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