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# Hyper-MAC

*soft combining scheme for fast data transmission*

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***Abstract:*** User equipment (UE), in general, has access to multiple radio access technologies (RATS). Besides primary base stations, secondary base-stations can also aid the UE's communication. Thus data can reach the UE via multiple secondary base-stations. Taking advantage of the benefits of using such multiple paths, we propose in this paper a soft combining scheme that improves block error rate (BLER) and throughput. We propose data duplication and integration at the Physical layer of layer 1 for downlink operations of 4G LTE, 5G NR, and WLAN. At the Physical layer of ENodeB (gnodeB), the data above the Physical layer is duplicated and sent to the UE via various paths. All these PDUs have the same sequence number (SN). Data from various networks are then linked together using the assigned SN at EnodeB to obtain an enhanced version of the PDU at UE. Although this technique involves new procedures when aggregating data at Physical layer, the average delay for a Physical-based aggregation scheme is very small compared with the conventional method because of the significant improvement in the block error rate (BLER) provided by the scheme over the BLER of the traditional standalone system. Finally, the BLER improvement results in throughput enhancement

***Index Terms - Diversity, Physical layer duplication, MRC, BER, BLER, PER, Throughput, LTE, WLAN, 5G NR.***

## I. INTRODUCTION

The 3GPP Release 15 [1] focuses on the duplication of PDCP layer information, where a similar PDCP PDU is duplicated and communicated through different RLC entities. Particular RLC PDUs can utilize a similar MAC entity employing carrier aggregation or pass through a completely different MAC element [2]. Multi-RAT associations can likewise accomplish duplication like LWA utilizing the Xw legitimate connection point. The essential point of duplication is to accomplish the unwavering quality of data. [3], [4]. Duplication is likewise proposed for video applications through a network coding structure in the PDCP layer [5]. There are exceptional difficulties related to PDCP layer information duplication [6]. As of now, choosing the right PDU is proposed while disposing of the others [4]. While this strategy works as long as one of the pathways achieves reliable communication, it fails if all paths (2 in the simplest instance) are in error, forcing the entire block to be retransmitted. Latency tends to rise since the round-trip time is so long in comparison to other fixed processing delays. [4]. We propose duplication of data at the transmitter's physical layer and merging of data at the receiver's physical layer. At the transmitter, the physical layer sends duplicate copies of data along numerous pathways, perhaps through different RATs. Multiple copies of data are integrated if all separate pathways fail their tests at the recipient. The Block error rate (BLER) is significantly reduced when data is combined in this way. The increase in BLER leads to an increase in throughput. These approaches will provide a higher reliability to cell edge users than a different RAT. Because a better BLER means fewer retransmissions, the average latency is improved as well. As a result, our combining technique might be a viable option for ultra-reliable low-latency communications (URLLC) Against this background, the following are our contributions in this paper: • At the physical layer, we suggest a soft-combining strategy and construct probability of error expressions for it. • We take an illustration of LTE helped by WLAN and 5G NR. We illustrate the performance advantages in terms of the block error rate (BLER) gained through simulations, and suggest that this increases throughput and latency in many circumstances of relevance for both selection combining and MRC-based methods. The remaining of the paper is as per the following. We initially present a nonexclusive hypothetical model of the framework in Section II. After the system model, we describe the physical layer based combining scheme in Section III. Then we derive the probability of error for the combining scheme in IV. Section V presents an example of the Multi connectivity-based data duplication. We perform simulation in Section VI and discuss the results and their interpretation Section VI. Finally, we conclude in Section VII.

## II. SYSTEM MODEL

Consider 3 distinct heterogeneous routes by which a UE can connect to the enodeB. These pathways are part of the same radio access technology (RATS), although they use separate serving eNodeBs or RATS.

A. Overview: The principal route of the UE without losing generality is i = 1. The secondary pathways are, i = 2, 3. Data is received concurrently by each of the three networks. To retrieve binary bits, the receiver decodes signals at the physical layer. Furthermore, the receiver saves the soft values (SVs) for each bit in terms of LLRs. The receiver has enough buffer capacity so that data sent across networks with shorter latency can wait for data from other networks if needed. An overview of the scheme is as shown in Fig. 1. We now explain the transmitter and the receiver parts.

B. Transmitter: Let the k length bit sequence of physical PDU be denoted as B = {b1, b2, . . . , bk}.Three separate pathways are used to send multiple copies of the same SN. The data at the physical layer is encoded after the inclusion of headers at all subsequent higher levels in an ni length bit sequence Ci, B = {ci,1, ci,2, . . . , ci,ni }. This is modulated using the appropriate scheme and is transmitted as signals represented by Xi , i ∈ {1, 2, 3}.

C. Receiver: The received signal Yi is as follows, Yi = Gi Xi + Zi , (1) where Gi denotes the random channel fading coefficient for path i, and Zi is additive white Gaussian noise. Let the bits to be decoded be denoted by C˜i,B = {c˜i,1, c˜i,2, . . . , c˜i,ni }. Each data path's data is decoded by the receiver, see Fig 2, and stores the SVs of the physical PDU, which are passed on to the physical layer if all the paths report erroneous detection. The physical layer in this situation combines the SVs and decodes data using the combined SVs. The physical layer then transmits the data to the upper levels, where the CRC check evaluates if the combination has recovered errors or whether retransmission is necessary.

1) Physical Layer Procedures at the receiver: We must de-interleave and de-scramble SVs at the receiver since the stored SVs are interleaved and scrambled. The process for deinterleaving SVs is easy and invertible, but the procedure for de-scrambling is as follows.

2) Descrambling of LLRS at the Physical layer: Denote the SV (the LLR) of the j−th bit by LLR(˜ci,j ) for network i, j = 1, . . . , ni}, the corresponding de-scrambled bit by LLR(ci,j ) and the de-scrambling sequence si,j . We now show that, if si,j = 0 then LLR(ci,j ) = −LLR(˜ci,j ), and if si,j = 1 then LLR(ci,j ) = LLR(˜ci,j ). This follows from the following explanation. The LR of a scrambled bit c˜i,j is

$$\Lambda(\widetilde{c_{i,j}}) = Pr(\widetilde{c_{i,j}} = 1|y)/Pr(\widetilde{c_{i,j}} = 0|y)$$

Also note that c˜i,j = ci,j ⊕ si,j . Thus ci,j = ˜ci,j ⊕ si,j . Now,

$$\Lambda(c_{i,j}) = \frac{Pr(c_{i,j} = 1|y)}{Pr(c_{i,j} = 0|y)} = \frac{Pr(\tilde{c}_{i,j} \oplus s_{i,j} = 1|y = 0)}{Pr(\tilde{c}_{i,j} \oplus s_{i,j} = 0|y = 0)} \quad (2)$$

$$\text{Thus if } s_{i,j} = 0, \text{ then } \Lambda(c_{i,j}) = \frac{Pr(\tilde{c}_{i,j} = 1|y)}{Pr(\tilde{c}_{i,j} = 0|y)} = \Lambda(\tilde{c}_{i,j}),$$

$$\text{whereas if } s_{i,j} = 1, \text{ then } \Lambda(c_{i,j}) = \frac{Pr(\tilde{c}_{i,j} = 0|y)}{Pr(\tilde{c}_{i,j} = 1|y)} = \frac{1}{\Lambda(\tilde{c}_{i,j})}$$

Finally, LLR(ci,j ) = ln Λ(ci,j ).

3) At the MAC and PHY sub-layer: Each MAC entity keeps the SVs for the transmitted MAC-payload at the MAC sublayer. The PHY defragments the SVs and solely decodes their headers, leaving the physical layer as SVs. Next, we'll look at the physical layer data combination.

## III. COMBINING DATA AT THE PHYSICAL LAYER

The soft-combining rule is deduced in this section.

A. Soft-combining The SVs corresponding to the physical PDU is combined in the physical layer. The SV of the transmitted bit bj from path i is equal to the log-likelihood ratio LLR(bi , j). Corresponding to each LLR(bi,j ) is the CSI Hi,j , where j = {1, 2, . . . , k}. Note that Hi,j is deduced from Gi . For the transmitted data rate, let Nc be the number of bits that span a coherence interval. If the bits dm,i is the data over a coherence interval, m = {1, 2, . . . , Nc} then for all those bits Hk,i = Gi . For the sake of simplicity, let us assume that the physical-layer employs BPSK modulation for all paths. As a consequence, the received baseband signal is now, Yi,j = Hi,jXj + Zi,j , where Xj = Xi,j , for all i, with Xj = 1 for bj = 1 and Xj = −1 for bj = 0. Let Y j = {Y1,j , Y2,j . . . YN,j}, and Hj = {Hi,j , H2,j . . . HN,j}. Note that at the receiver Y j is the received signal and Hj is the estimated channel gain. Now the LLR for bj is,

$$\text{LLR}(b_j) = \ln\left(\frac{f_X(X_j = 1|Y_j, H_j)}{f_X(X_j = -1|Y_j, H_j)}\right)$$

$$\frac{f_X(X_j = 1|Y_j, H_j)}{f_X(X_j = -1|Y_j, H_j)} = \frac{f(Y_j|H_j, X_j = 1)}{f(Y_j|H_j, X_j = -1)}$$

The noise Zi,j is Gaussian iid over time and paths. Given Xj and Hi,j at the receiver, Yi,j s are independent over i. Thus,

$$\frac{f(Y_j|H_j, X_j = 1)}{f(Y_j|H_j, X_j = -1)} = \frac{\exp\left(-\sum_{i=1}^{3} \frac{|Y_{i,j} - H_{i,j}|^2}{\sigma_i^2}\right)}{\exp\left(-\sum_{i=1}^{3} \frac{|Y_{i,j} + H_{i,j}|^2}{\sigma_i^2}\right)}$$

The LLR thus becomes,

$$\text{LLR}(b_j) = 2\sum_{i=1}^{3} \frac{\Re\{Y_{i,j} H^*_{i,j}\}}{\sigma_i^2}$$

## IV. PROBABILITY OF ERROR

The probability of error for equiprobable BPSK symbols is pso = Pr{LLR(bj ) > 0|bj = 0}. Note that for BPSK bj = 0 corresponds to Xj = −1. Also, we drop the subscript j as the error performance is iid over j. Thus

$$pso = \Pr\left\{\sum_{i=1}^{3} \frac{\Re\{YiH{*}i\}}{\sigma i^{\wedge}2} > 0 | X = -1\right\}$$

Now given X = −1, Yi = −Hi + Ni. Thus ℜ{YiH∗i } = −|Hi|^2 + ℜ{NiH∗i }. Since the effect of conditioning has been taken care, we have

$$pso = \Pr\left\{\sum_{i=1}^{3} \frac{\Re\{YiH{*}i\}}{\sigma i^{2}} > \sum_{i=1}^{3} \frac{|Hi|^{\wedge}2}{\sigma i^{\wedge}2}\right\}$$

The pso is found by averaging over H,

$$pso = E_H\left[Q\left(\sqrt{2\sum_{i=1}^{3} \frac{|Hi|^{\wedge}2}{\sigma i^{\wedge}2}}\right)\right]$$

| MAC parameters | 5G | LTE | WiFi |
|---|---|---|---|
| Access Mode | FDD | FDD | CSMA/CA |
| Transmission | Downlink | Downlink | Downlink |
| Fading Model | Rayleigh | Rayleigh | Rayleigh |
| Number of frames | 25 | 50 | 500 (packets) |
| TTI | 1 ms | 1 ms | 1 ms |
| Frame duration | 10 ms | 10 ms | 1 ms |
| Bandwidth | 20 MHz | 20 MHz | 40 MHz |

| Physical parameters | sub-scenario 1 | | sub-scenario 2 | | sub-scenario 3 | |
|---|---|---|---|---|---|---|
| | 5G | LTE | 5G | WiFi | LTE | WiFi |
| MCS | 23 | 12 | 23 | 1 | 12 | 1 |
| Peak data rate (Mbps) | 30 | 27.5 | 30 | 30 | 27.5 | 30 |
| Buffer size (Mb) | 30 | 30 | 30 | 30 | 30 | 30 |
| SNR (dB) | 10, 11, 12 | 10, 12, 14 | 10, 11, 12 | 11, 11.5, 12 | 10, 12, 14 | 11, 11.5, 12 |
| Transport block size (bits) | 30216 | 30216 | 30216 | 30216 | 30576 | 30576 |
| Simulation time (ms) | 4500 | | 4500 | | 4500 | |

fig 1. Simulation Parameters

## V. COMPATIBLE DATA RATES

To support the primary, the secondary links must attain higher data rates than the primary. We call such a collection of rates compatible data rates. In many circumstances, compatible rates can be achieved by modifying various data rate parameters. We'll illustrate in the following section, for example, that there are a variety of compatible rates that might allow WLAN IEEE 802.11ac to function with LTE and 5G NR.

A. LTE peak rate:

The frame duration is 10 milliseconds, according to 3GPP version 12 [10]. Each frame is split into ten subframes, each with a length of $T_{s,l}$ = 1 ms. $T_s$ = 2 time slots make up each subframe. At least one physical resource block is allotted to each UE (PRB).

Nc = 12 subcarriers make up a PRB, each with a fixed bandwidth of $F_L$ = 15 kHz. In addition, each PRB has Ns = 7 OFDM symbols when using conventional cyclic-prefix and Ns = 6 when using extended cyclic-prefix. For M QAM, each OFDM symbol has $b_L$ bits, where b = log2 M. Let BL represent a UE's available bandwidth. Let $N_{prb}$ be the number of PRBs assigned to a UE to correspond to this bandwidth. Let the code rate be Cl. For MIMO systems let the multiplexing gain be Gl. The peak data rate for UE is then,

$$r_{LTE} = C_l G_l \frac{N_{prb} N_c N_s T_s b_L}{T_{s,l}}$$

As an example rate calculation, suppose a total bandwidth of B = 10 MHz, is available to a UE. This corresponds to Nprb = 50. Assuming, Cl = 3/4 transmission, 4× 4 MIMO with normal cyclic-prefix and 16− QAM, we have the rate

$$r_{LTE} = \frac{2s \times 50 \times 12 \times 7 \times 2 \times 4}{10^{-3}} = 96.13\text{Mbps}.$$

B. WLAN peak rate:

According to [11], there are a predetermined number of subcarriers Nw in the 802.11ac standard, each with a sub-carrier spacing of Fw = 312.5 KHz. As a result, the symbol's duration is 3.2 seconds. Ts,w = 3.6s for short interval and 4s for long interval. The peak data rate for bandwidth Bw for M QAM modulation with coding rate Cw and multiplexing gain Gw is

$$r_{WLAN} = C_W G_W \frac{N_w b}{T_{s,w}}$$

As an example, for Bw = 20 MHz, Nw = 56. If 16-QAM is used with a short guard interval with Cw = 3/4 and Gw = 4, we have

$$rWLAN = \frac{3\times 56\times 4\times 10^{6}}{3.6} = 178\text{Mbps}.$$

C. 5G-NR PEAK DATA RATE:

As per [12], the maximum data rate computed for a given number of aggregated carriers in a band or band combination is as follows.

$$rNR = \sum_{j=1}^{J}\left(v_L^{(j)} Q_m^{(j)} f^{(j)} R_m \frac{N_{\mathrm{PRB}}^{\mathrm{BW(j)},\mu} 12}{T_s^{\mu}}\left(1 - OH^{(j)}\right)\right)$$

wherein J is the number of aggregated component carriers (CC) in a band or band combination, Rmax = 948/1024 (for LDCP codes). For the j-th CC, $v_L^{(j)}$ is the maximum number of supported layers or in other words, the number of MIMO data-streams supported. Also, $Q_m^{(j)}$ is the maximum supported modulation order. Also, $f^{(j)}$ is the scaling factor and can take the values 1,0.8,0.75, and 0.4. The scaling factor incorporates the relationship between the maximum number of layers and the band combination's maximum modulation order. If the maximum number of layers and the maximum number of modulation orders are per band and per band combination, the scaling factor becomes unnecessary. For the j-th CC, $v_L^{(j)}$ is the maximum number of supported layers or in other words, the number of MIMO data-streams supported. Also, $Q_m^{(j)}$ is the maximum supported modulation order μ.

## VI. Conclusion

In this paper, we propose a soft-combining strategy for 5G networks at the physical layer. The proposed technique efficiently mixes the physical layer PDUs arriving at the UE from separate pathways when the CRC and HARQ processes fail. To the best of our knowledge, this is the first time an optimum physical layer level duplicated data combining approach has been suggested. Calculations showed that using correctly integrated PDUs reduces the BLER, increasing throughput and latency in a variety of circumstances. Furthermore, under various interest regimes, the average latency is improved, particularly when the SNR for a given MCS is low. The programme will surely aid in the development of 5G and next-generation wireless network techniques for both the eMBB and the URLLC applications.

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