IEEE **WAMICON 2018**, April 9-10, 2018

Reliable and Resilient Coordinated Multi Point Fronthaul Networks

Nabeel I. Sulieman, *Student Member, IEEE*, Eren Balevi, *Member, IEEE*, and Richard D. Gitlin, *Life Fellow, IEEE*
Department of Electrical Engineering
University of South Florida
Tampa, Florida 33620, USA

Email: nis@mail.usf.edu, erenbalevi@mail.usf.edu, richgitlin@usf.edu

Abstract— **Very fast link failure recovery and high throughput can be achieved via the synergistic combination of Diversity and Network Coding (DC-NC), an open-loop coding technique, in a wide variety of network architectures. In this paper, DC-NC is applied to enable recovering from a wireless link/node failure in the fronthaul portion of downlink Coordinated Multi Point (CoMP) 5G wireless network in a C-RAN environment. Our results demonstrate that by utilizing DC-NC coding in CoMP systems, resource consumption is reduced by about one-third and ultra-reliability with near-instantaneous fault recovery is achieved.**

Keywords—5G, CoMP, Diversity Coding, fronthaul, Network Coding, reliability, throughput

I. INTRODUCTION

Wireless 5G networks require ultra-low latency communications for many key applications, as well as high throughput and reliability [1]. Link/node failure is one of the principle contributors that increases latency, reduces system throughput, and decreases reliability. Synchronous Optical Networking (SONET) and *p*-cycle ring are examples of technologies that used to protect wired communication networks from link and node failures [2]-[3]. However, these solutions are not appropriate for wireless fronthaul network configurations, as their delay performance is still considered to be too high to meet 5G ultra-low latency requirements. Many applications in 5G communication systems will require very low delay (around 1ms) and high reliability, and solutions need to be developed to address these two challenges. Near-instantaneous recovery from fronthaul wireless link failures is essential to improve reliability and enable very low delay networking. This can be achieved by Diversity Coding [4]-[5], which predates Network Coding [6], as it is a feedforward technique that uses forward error control technology over diverse paths, and provides near-instantaneous recovery of the lost data is possible as soon as the failure is detected with no need to retransmit messages and perform rerouting.

In [7] and [8] Diversity Coding is applied to a C-RAN (Cloud Radio Access Network) network to enhance performance by improving the reliability with near-instant link/node failure recovery. C-RANs are one of the evolving 5G wireless network architectures, where distributed Remote Radio Heads (RRHs) are connected to a centralized baseband unit (BBU) via a *fronthaul* network. This architecture enables very low latency, high bandwidth, accurate synchronization, and interference management capabilities [9]. Also, it was shown that multiple simultaneous link failures can be recovered via Diversity Coded systems [8]. Although ultra-low latency and high reliability are very important in C-RANs, high data rate coverage is another important factor that effects C-RAN performance. One of the techniques to improve high data rate coverage is by managing the interference and mitigating inter-cell interference using Coordinated Multi Point (CoMP) technology [9]. Coordinated Multi Point (CoMP) shares both data and channel state information (CSI) among neighboring cellular base stations (BSs) to coordinate their transmissions in the downlink and jointly process the received signals in the uplink. In this way, harmful inter-cell interference becomes useful signals, enabling significant power gain, channel rank advantage, and/or diversity gains [9]-[10]. A challenge in the implementation of CoMP is reducing the additional network resources that are used for simultaneous redundant transmissions to several RRHs. This issue can be addressed by Network Coding [6], also called Linear Network Coding (LNC), which is a particular form of coding at a network node. LNC improves network throughput, which in turn reduces consumption of network resources and saves system bandwidth for data broadcasting/multicasting [6].

A new coding technique called DC-NC coding, based on the synergistic combination of Diversity Coding (DC) and Network Coding (NC) was recently introduced [11]. DC-NC can enable ultra-low latency communications systems, enhance network resource utilization for broadcasting/multicasting applications, and improve wireless fronthaul network reliability. Latency is lowered owing to the open-loop nature of DC-NC coding.

The contribution of this paper is to extend the application of DC-NC coding to downlink CoMP within a C-RAN to decrease wireless fronthaul resource consumption, enhance wireless fronthaul C-RAN reliability, and enable ultra-low recovery time.

The rest of this paper is organized as follows: Section II describes the network topology based on C-RANs where downlink CoMP is applied to several RRHs, which are connected to the BBU via wireless links. Section III demonstrates the benefit of the synergistic combination of Diversity and Network Coding to enable less resource consumption and faster recovery from multiple simultaneous link failures in wireless fronthaul networks that utilize downlink CoMP. The paper ends with concluding remarks in Section IV.

II. SYSTEM MODEL

A C-RAN separates traditional base station functions by virtualizing and centralizing processing and control functions in the BBU of the core network, and distributing communications via RRHs at the cell sites to perform the radio functions with ability to manage the interference [9], [12]-[13]. As discussed above, CoMP may be used to improve interference management capabilities in C-RANs. CoMP has been standardized in Release 11 of the LTE mobile network specifications [10]. To implement CoMP, a set of cells, called a CoMP set, where each cell is served by a RRH, team up to serve a single or multiple user equipment (UEs) based on feedback from the user(s). Fig. 1 shows three cells (1, 2, and 3), each represented by a RRH, are grouped as a CoMP set to serve a UE. As all RRHs are controlled by the same BBU pool, very tight synchronization and coordination among the RRHs in a CoMP set can be easily achieved [9], [14], [15].

There are three ways to deploy downlink CoMP: the simplest way is called Coordinated Scheduling/ Coordinated Beamforming (CS/CB) where the UE deals with only one RRH (called the serving RRH) while other RRHs in the CoMP set help in preventing interference [9], [14]. The second type of CoMP is an extension of the above scheme which is called Dynamic Point Selection (DPS). In this scheme, the required data for a particular UE is made available to all RRHs in a CoMP set. However, only one RRH deals with a mobile at a given point of time. The BBU decides which one should do the actual transmission based on the quality of its transmission path to the UE [9], [14].

The last and the most advanced CoMP scheme is Joint Transmission (JT). Here, all RRHs in the CoMP set receive the required data and they simultaneously transmit the same information with accurate timing to the user(s) with the expectation of achieving a high SINR. Although, this scheme generally guarantees high data rate coverage, it consumes several RRHs resources [9], [14].

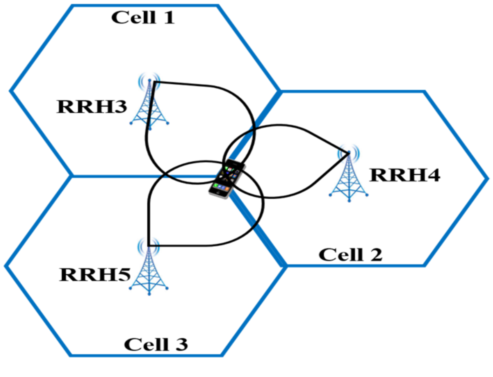

Fig. 1. Group of cells team up as a CoMP set to serve a UE in wireless fronthaul C-RAN.

In this paper, we focus on applying DC-NC to downlink JT-CoMP in wireless fronthaul C-RAN to enhance resource utilization and improve the reliability with ultra-low recovery time. We consider the C-RAN topology where most RRHs are connecting directly to the BBU/BBUs pool via wireless links. Moreover, RRHs are connected to each other in a general mesh topology as illustrated in Fig. 2. Furthermore, downlink JT-CoMP is used, where CoMP set cells are represented by RRH3, RRH4, and RRH5. This CoMP set serves a UE as shown in Fig. 1.

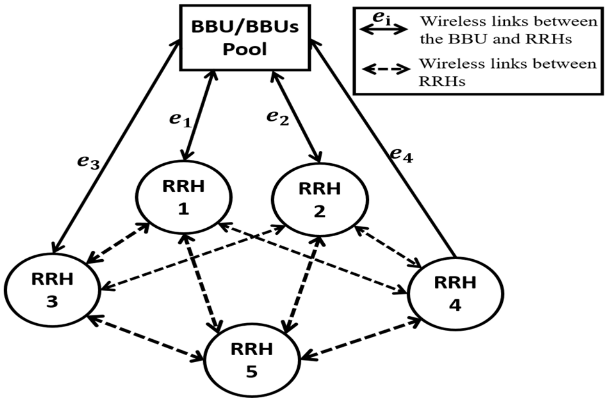

Fig. 2. Example C-RAN with wireless fronthaul network links.

III. APPLYING DC-NC CODING TO COMP IN C-RAN

As a 5G wireless C-RAN utilizes downlink JT-CoMP to mitigate inter-cell interference, it needs to broadcast downlink information to several RRHs called a CoMP set. The redundant transmission consumes network resources. Reducing overall network resource consumption is important to overcome the limitations of wireless link capacity. In addition, due to weather changes or other environmental factors such as blockage, link failures can occur. To enhance resource utilization and improve the reliability with near instant link/node failure recovery, the DC-NC technique is very appealing, as depicted below.

Fig. 3 shows the application of DC-NC coding to downlink JT-CoMP in a 5G wireless fronthaul C-RAN network, where a link failure is considered. In this scenario, a direct wireless link between the BBU/BBUs pool and most RRHs is considered. In addition, RRHs are connected to each other by wireless links. However, when the distance between RRH5 and BBU/BBUs pool is considered to be too great, no direct link exists with the BBU/BBUs pool, but RRH5 is connected to other RRHs and thus can reach the BBU/BBUs pool. For simplicity, the connections between the user(s) and the CoMP set RRHs are not shown in Fig. 3. However, it is similar to that in Fig. 1. Each fronthaul link is bi-directional. In this study, a downlink point-to-multipoint network topology is considered to model the application of downlink JT-CoMP. The CoMP set RRHs are RRH3, RRH4, and RRH5. So that using the DC-NC coding method, four disjoint paths are needed to broadcast two data streams (for the same user or each one for different user) from the BBU/BBUs pool to all RRHs in the CoMP set. Utilizing direct links, data streams x_1 and x_2 are sent from the BBU/BBUs pool to RRH3 and RRH4 respectively. In addition, coded data c_1 and c_2 are formed in the BBU/BBUs pool as follows:

$$c_1 = \beta_{11}x_1 + \beta_{21}x_2, \tag{1}$$
$$c_2 = \beta_{12}x_1 + \beta_{22}x_2, \tag{2}$$

then sent to RRH1 and RRH2 respectively. Where $[\beta_{ij}]$ is the parity generator matrix for c_1 and c_2. Note that as multiplication and summation are performed in $GF(2^m)$, they correspond to the AND and XOR operations respectively. RRH5 receives x_1

and x_2 directly from RRH3 and RRH4 respectively. Hence, RRH5 receives both broadcasted data streams. RRH1 sends c_1 to RRH3 and RRH4. Coded data c_1 and data stream x_1 are decoded in RRH3 to obtain x_2 as follows:

$$\tilde{c}_1 = c_1 + \beta_{11}\, x_1, \tag{3}$$

and applying (1) to (3),

$$\tilde{c}_1 = \beta_{11}x_1 + \beta_{21}x_2 + \beta_{11}x_1 = \beta_{21}x_2, \tag{4}$$

$$x_2 = \tilde{c}_1/\beta_{21}. \tag{5}$$

Note that the coefficients β_{ij} are fixed and known at all nodes. Similarly, c_1 and x_2 are decoded in RRH4 to get x_1 as follows:

$$\tilde{c}_1 = c_1 + \beta_{21}\, x_2, \tag{6}$$

and applying (1) to (6),

$$\tilde{c}_1 = \beta_{11}x_1 + \beta_{21}x_2 + \beta_{21}x_2 = \beta_{11}x_1, \tag{7}$$

$$x_1 = \tilde{c}_1/\beta_{11}. \tag{8}$$

If only standard routing were allowed, then the link that connects the BBUs pool and RRH1 would be only able to carry x_1 or x_2, but not both. Suppose we send x_1 through this link; then RRH3 would receive x_1 twice and not know x_2 at all. Similarly, Sending x_2 poses the same problem for the RRH4. So that routing is insufficient because no routing scheme can transmit both x_1 and x_2 simultaneously to both destinations. Hence, by encoding the data x_1 and x_2 at the BBU, the throughput is improved by one-third in this application. This illustrated the network resource utilization enhancement of DC-NC coding, which is similar to that of Network Coding.

Wireless fronthaul network reliability can be improved by transmitting c_2 from RRH2 to the CoMP set RRHs. The coded data c_2 will be ignored when there is no link failure. In the presence of a link failure, for example if the link from the BBU/BBUs pool to RRH3 fails, RRH3 detects the failure then recovers x_1 and x_2 by utlizing c_1 and c_2 as follows:

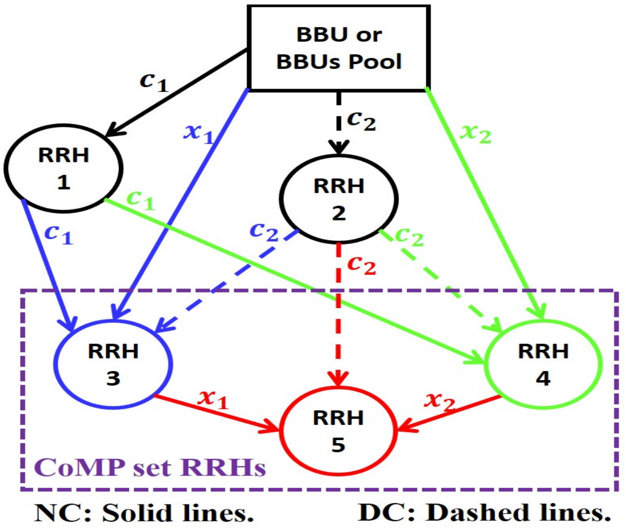

Fig. 3. DC-NC coding applied to downlink JT-CoMP in wireless fronthaul C-RAN, where the CoMP set RRHs are RRH3, RRH4, and RRH5.

Expressing (1) and (2) in a matrix form

$$\begin{bmatrix} c_1 \\ c_2 \end{bmatrix} = \begin{bmatrix} \beta_{11} & \beta_{21} \\ \beta_{12} & \beta_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}, \tag{9}$$

Using the inverse matrix transform, x_1 and x_2 can be easily recovered. The parameters β_{ij}'s should be chosen such that $\beta_{11}, \beta_{21}, \beta_{12}$ and β_{22} are linearly independent.

Therefore, RRH3 obtains x_1 and x_2 as follows:

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \beta_{11} & \beta_{21} \\ \beta_{12} & \beta_{22} \end{bmatrix}^{-1} \begin{bmatrix} c_1 \\ c_2 \end{bmatrix}. \tag{10}$$

Furthermore, if c_1 lost, RRH3 has $x_1$directly and c_2 then can quickly and easily form

$$\tilde{c}_2 = c_2 + \beta_{12}x_1, \tag{11}$$

and applying (2) to (11),

$$\tilde{c}_2 = \beta_{12}x_1 + \beta_{22}x_2 + \beta_{12}x_1 = \beta_{22}x_2 \tag{12}$$

$$x_2 = \tilde{c}_2/\beta_{22}. \tag{13}$$

Similarly, data streams x_1 and x_2 can be recovered at RRH4. However, since c_1 will not be received by RRH5, if x_2 is lost, it can be easily and quickly obtained as shown in (11)- (13). Also, if x_1 is lost, it can be easily and quickly obtained as follows:

$$\tilde{c}_2 = c_2 + \beta_{22}x_2, \tag{14}$$

and applying (2) to (14),

$$\tilde{c}_2 = \beta_{12}x_1 + \beta_{22}x_2 + \beta_{22}x_2 = \beta_{12}x_1 \tag{15}$$

$$x_1 = \tilde{c}_2/\beta_{12}. \tag{16}$$

As DC-NC coding has the ability to simultaneously recover from one link failure at each destination node [11], hence, in this example for a fronthaul network, DC-NC can recover from three link failures simultaneously (one failure for each targeted RRH), but NOT two or more links for the same RRH. In general, when link failures are associated with different RRHs, then DC-NC can recover from these simultaneous failures. For example, when c_1 at RRH3, x_2 at RRH4, and x_1 at RRH5 fail simultaneously, DC-NC can recover from all these simultaneous failures since each failure belongs to a different RRH. However when more than one failure belongs to the same RRH , DC-NC *cannot* recover from these failures. For example, when c_1 and x_1 fail simultaneously at RRH3, DC-NC cannot recover because both failures belong to the same RRH.

Furthermore, in addition to link failure recovery, DC-NC coding can recover from one intermediate node failure [11] such as RRH1 because this corresponds to simultaneous link failures that are associated with different CoMP set RRHs. Also, when RRH2 fails, protection of the network will be lost i.e. c_2, but, if this is the only failure, successful data communication can still be achieved. However, when more than one node failure occurs, DC-NC *cannot* recover from these failures because this will cause two or more link failures at the same targeted RRH. For example, when RRH1 and RRH2 fail simultaneously, DC-NC cannot recover since c_1 and c_2 will be lost simultaneously.

In this example network, we utilized four redundant links to protect from one link failure at each CoMP set RRH, which consists three RRHs. To protect the JT-CoMP network completely, another set of four links should be utilized as shown in Fig. 4 (note the addition of RRH6 and distribution of coded data c_3). Hence, each RRH at the CoMP set has the ability to tolerate two simultaneous link failures. As only two links are required for each RRH at the CoMP set in this example network to deploy the JT-CoMP operation, complete protection to the network at the expense of redundant transmission links is provided. In general, to tolerate n link failures for each RRH at the CoMP set that contains j RRHs, $jn + n$ redundant links are required.

It is clear that this work does not need to simulation because the link failure is taken into account regardless of the failure reason and it is shown mathematically how the JT-CoMP operation can be enhanced and protected by DC-NC coding scheme. The recovery latency is lower bounded by the time it takes to detect a facility failure which will vary from system to system.

This will enhance network reliability with ability to tolerate multi-link failures at the same time in addition to near-instant link/node failures recovery. Therefore, both reliability and network resource utilization are improved by applying the DC-NC coding scheme.

Although in this study, we solely focused on applying the DC-NC coding scheme in a downlink JT-CoMP with a wireless fronthaul network that can simultaneously tolerate multi-link failures, our future work will investigate this approach to more general and complex network topologies that include optical and wireless links.

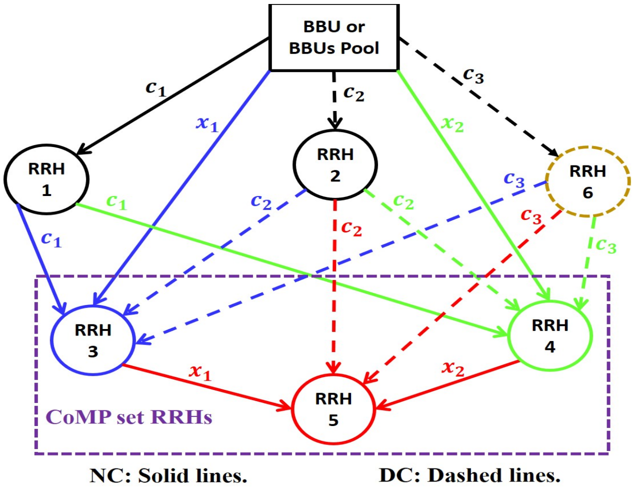

Fig. 4. DC-NC coding applied to downlink JT-CoMP in wireless fronthaul C-RAN. Two simultaneous link failures can be tolerated (Complete protection).

IV. CONCLUSIONS

This paper presented the application of our recently introduced coding technique, DC-NC, that synergistically combines Diversity and Network Coding, to improve the performance of downlink JT-CoMP in 5G wireless fronthaul C-RANs. In this study, (most) all RRHs in C-RAN are connected directly to the BBU/BBUs pool via wireless links. It is shown that DC-NC has the ability to simultaneously recover from multiple link failures when these failures are associated with different RRHs. In addition, DC-NC coding can recover from one intermediate node failure. Furthermore, DC-NC networks can tolerate n link failures for each RRH at the CoMP set that contains j RRHs, however, $jn + n$ redundant links are required. Hence, applying DC-NC coding reduces the resource consumption in the network by about one-third, while simultaneously minimizing the impact on latency of multiple link/node failures in wireless fronthaul network links.

ACKNOWLEDGMENT

Nabeel I. Sulieman is supported by the Higher Committee for Education Development in Iraq (HCED-IRAQ).

REFERENCES

[1] H. Tullberg *et al.*, “The METIS 5G system concept: meeting the 5G requirements,” *IEEE Commun. Mag.*, vol. 54, no. 12, pp. 132-139, Dec. 2016.

[2] S. Avci and E. Ayanoglu, “Recovery from link failures in networks with arbitrary topology via Diversity Coding,” in Proc. *IEEE Globecom*, Houston, TX, Dec. 2011.

[3] J.-P. Vasseur, M. Pickavet, and P. Demeester, Network recovery: protection and restoration of optical, SONET-SDH, IP, and MPLS. Elsevier, 2004.

[4] E. Ayanoglu, C.-L. I, R. D. Gitlin, and J. E. Mazo, “Diversity Coding: Using error control for self-healing in communication networks,” in Proc. *IEEE INFOCOM’90*, San Francisco, CA, June 1990, pp. 95–104, vol. 1.

[5] E. Ayanoglu, C.-L. I, R. D. Gitlin, and J. E. Mazo, “Diversity Coding for transparent self-healing and fault-tolerant communication networks,” IEEE Trans. Commun., vol. 41, pp. 1677–1686, Nov. 1993.

[6] R. Ahlswede, N. Cai, S.-Y. R. Li, and R. W. Yeung, “Network information flow,” IEEE Trans. Inform. Theory, vol. 46, no. 4, pp. 1204–1216, July 2000.

[7] N. Sulieman, K. Davaslioglu, and R. D. Gitlin, “Link failure recovery via Diversity Coding in 5G fronthaul wireless networks,” *IEEE Wireless and Microwave Technology Conference,* Cocoa Beach, FL, April 2017.

[8] N. Sulieman, K. Davaslioglu, and R. D. Gitlin, “Diversity coded 5G fronthaul wireless networks,” *IEEE Wireless Telecommunication Symposium,* Chicago, IL, April 2017.

[9] A. Checko *et al.*, "Cloud RAN for mobile networks-A technology overview," *IEEE Comm. Surveys and Tutorials*, vol. 17, no. 1, pp. 405-426, First Quarter 2015.

[10] “Coordinated multi-point operation for LTE physical layer aspects V 11.1.0,” Sophia-Antipolis Cedex, France, TR 36.819 V11.1.0 (2011-12), Dec. 2011.

[11] N. I. Sulieman, E. Balevi, K. Davaslioglu, and R. D. Gitlin, “Diversity and Network coded 5G fronthaul wireless networks for ultra reliable and low latency communications,” *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Montreal, QC, Canada, Oct. 2017.

[12] Ericsson, "Centralized RAN and fronthaul", Whitepaper, May 2015. [Online]. Available: http://www.isemag.com/wp-content/uploads/2016/01/C-RAN_and_Fronthaul_White_ Paper.pdf

[13] Alcatel-Lucent, "Mobile fronthaul for Cloud-RAN deployment", Whitepaper, March 2014. [Online]. Available: http://www.tmcnet/tmc/whitepapers/documents/whitepapers/ 2014/10051-mobile-fronthaul-cloud-randeployment.pdf

[14] J. Lee *et al.*, “Coordinated multipoint transmission and reception in LTE advanced systems,” *IEEE Commun. Mag.*, vol. 50, no. 11, pp. 44–50, Nov. 2012.

[15] H. Jinling, “TD-SCDMA/TD-LTE evolution—go green,” in *Proc. IEEE ICCS*, Singapore, Nov. 2010, pp. 301–305.