Cooperative Communications for Internet of Everything in B5G/6G Hybrid and Ubiquitous Networks: Foundation, Further Optimization and Solutions

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Abstract—Although Cooperative Communication (CC) already exists in 4G/4G LTE/5G, performance improvement is just not enough, hence, how to apply CC technology in B5G/6G to achieve Internet of Everything and improve communication quality significantly are one of the most important issues. As 5G communications standard is gradually established recently, CC has been one of the most critical communication technologies which plays a founding role on Internet of Everything in B5G/6G networks, and core communications technologies with CC are further studied to substantially improve communication quality and develop new communications scenarios for B5G/6G ubiquitous networks. Considering that CC has been regarded as foundation theory which widely exists in future multiple B5G/6G hybrid scenarios, such as, Cognitive Internet of Things (CIOT) networks, UAVs communications, air-space-ground of integrated networks, underwater acoustic communication and so on, besides it is closely combined with other key technologies, for examples, Massive MIMO, NOMA, Full-duplex transmission, Polar code and so on. Hence, in this paper we review foundation of CC for Internet of Everything in B5G/6G multiple heterogeneous networks, and compare fundamental CC algorithms to reveal key of performance improvement. Furthermore we propose that collective communications ideology is theory of foundation to realize and optimize communications for arbitrary two points as source/destination devices, sensors, relays, IOT nodes and so on in future.

Index Terms—B5G/6G, Internet of Everything, collaborative ideology, ubiquitous networks

INTRODUCTION

With rapid development of wireless communications, 5G has been gradually applied in all aspects of work, study and life, in the light of further improving communication quality, recently research plans of B5G/6G are proposed to develop related core communications techniques [1]. Cooperative Communications (CC) is regarded as pivotal technology to enable arbitrary two points (such as, source/destination devices, sensors, relays, IOT nodes and so on) communication for Internet of Everything, hence it is very important for future communication to study essential communications technologies based on CC in multiple B5G/6G heterogeneous networks, and consider optimizing transmission performance with different CC topology networks [2, 3].

CC is extensively existed in hybrid B5G/6G networks, for example, Cognitive Internet of Things (CIOT) networks, UAVs communications, space-ground integration networks, underwater acoustic communication, free space optical communication, smart city, vehicular networks, cloud-fog-edge intelligent computing and so on. In these communication scenarios, CC plays an auxiliary role to establish inter-communication for source and destination, and optimize device-to-device transmission performance [4-6].

On the other hand, in order to comprehensively improve transmission quality more effectively, critical communication technologies are closely linked with CC, hence, multiple relays with massive MIMO, massive access with sensors, space-air-ground integrated network with relays of air and space, ultra dense networks with multiple IOT nodes, full-duplex cooperative transmission, etc are optimized issues that should be studied deeply [1, 4, 5].

Moreover, effectiveness of CC algorithms are fundamental problems that contain how to optimize performance and build more efficiently transport network topology. CC algorithms mainly include single node selection and multi-node selection, at present, the former contains best node selection, N-th best node selection, partial node selection and so on [7, 8], the latter contains several classical and available nodes subsets selection. Generally speaking, algorithms based on subsets selection are relatively more effectively than algorithms based on single selection [9-13].

Stated thus, this work reviews CC with multiple B5G/6G scenarios, and highlights its foundation role in integrated networks, we compare and analyze how important techniques ulteriorly perfect and improve communication transmission through efficient collaborate schemes. In addition, we sum up a series of issues of typical algorithms to make comparison and analysis in several aspects of performance, applicable scenarios and their advantages and disadvantages, at last we propose that development direction of future communication – CC lays the foundations of Internet of Everything, and it is one of most
important research hotspots to deeply study and apply CC in future communication with collaborate idea.

CC IN B5G/6G HYBRID AND UBIQUITOUS NETWORKS

B5G/6G HYBRID AND UBIQUITOUS NETWORKS

In this part, as shown in Fig.1, firstly we set up B5G/6G ubiquitous CC networks with multiple related communication scenarios that are developed in recent years, and point out that key of achieving communication and optimizing communication quality is to realize different CC networks interconnection efficiently. Hence, for one thing, we can expand communication coverage widely to weak signal area through building and connecting to local CC networks, for another, it is critical to select appropriate relays/sensors/IOT nodes in different networks, so that wider ubiquitous networks would be established effectively to ensure high quality of communication transmission.

Secondly, from Fig.1, we present B5G/6G ubiquitous networks with several fundamental CC networks, for example, it is shown that if one of arbitrary mobile users A in left cellular CC networks wants to communicate with one of fixed arbitrary user B in right cellular CC networks, A can connect to B with multiple CC networks at the same time, further in this process by means of advanced artificial intelligence and signals processing techniques, A will communicate with B more fast and reliably with the aid of newly established optimized transmission heterogeneous networks. To sum up, in view of constantly integrating all sorts of independent CC networks, it is challenging to expand communication coverage region and develop corresponding optimized networks structure for a long time to come.

TABLE I

RELATED OPTIMIZED TECHNIQUES IN B5G/6G HYBRID AND UBIQUITOUS NETWORKS
**Related optimized techniques**

- Massively MIMO
- OFDMA.
- FD-duplex communications.
- Device-to-Device optimized communications.
- MM-wave communications.
- Non-orthogonal multiple access (NOMA, SCMA, PDMA).
- Intelligent computation (intelligent cloud-fog-edge computation).

**B5G/6G communications scenarios**

- UAVs’ communications
- *CC networks in group of UAVs*
- *Point-to-point communication with CC networks of UAVs*
- Cognitive Internet of Things
- *Multiple access*
- *Multiple IOT nodes/sensors CC networks under licensed and unlicensed spectrum*
- Space-air-ground integrated networks
- *Satellite/plain/ground communication device CC networks*
- Underwater acoustic communication
- *Underwater sensors CC networks*
- Free space optical (FSO) communication
- *Line-of-Sight (LOS) and short-distance FSO/RF relay CC networks*
- Vehicular networks
- *CC internet of vehicles*

Furthermore, combined with Fig.1 and Fig.2, we observe that arbitrary multiple communication nodes in Fig.1 can achieve highly quality of inter-communication for Internet of Everything in Fig.2, so after creating integrated B5G/6G networks, we should set up extremely efficient data-transmission link by the aid of synthetic intelligence transmission algorithms which takes artificial intelligence as the core technique. Thus, as Fig.2 shows, random sources/destinations/relays/sensors/IOT nodes or other communication nodes, will be contained in B5G/6G hybrid and ubiquitous CC intelligent transmission systems, and the wider networks will mix various key nodes broadly.

**Combination of Techniques in B5G/6G Networks**

On the basis of proposed converged B5G/6G networks, in order to substantially improve communication performance, we review that development and application of related core technologies in B5G/6G hybrid CC networks. In table I, on one hand, we sum up respective CC networks features in different communication scenarios to present varied and unique characteristics of collaborative transmissions, on another critical involved technologies of B5G/6G are widely applied in correlative networks and particular scenarios, such as, Massive MIMO, OFDMA, FD-duplex communications, Device-to-Device optimized communications, MM-wave communications, Non-orthogonal multiple access (NOMA, SCMA, PDMA), Intelligent computation (intelligent cloud-fog-edge computation), moreover, several specific techniques listed above are comprehensively related to significantly promote service quality and extensively used in the future networks.

**Fundamental CC Algorithms**

**Problems of CC Algorithms**

Along with complex B5G/6G CC networks that are discussed above, so far there are mainly several problems of major respects that should be considered thoroughly, examples are as follows.

*Paths selection and optimization. For arbitrary two nodes in hybrid networks, how to develop optimized and sub-optimized selected paths are very important works, main problems include dual-hop path selection and multiple hops paths selection, thus one or more practical paths should be computed and selected to enable and optimize efficiency, reliability and security of transmission system.*

*Single node or nodes subsets selection. In view of above-paths discussion, it points to a deeper problem-nodes selection that which ones should be chosen. With regard to collective communications of multiple nodes, advanced subsets method will lead to appropriate selected nodes to establish multi-path link networks, in addition, considering optimizing paths selection and nodes selection at the same time is a more comprehensive problem.*

*Efficient resource allocation. Authors propose effective resource allocation schemes to assign fixed total power to source/destination/CC devices and selected nodes reasonably, on this basis, analyze correlative optimization process of performance in different communication systems.*

*NP-hard problem with multi-variants. Due to various nodes characteristics of CC, such as, size of power of CC nodes, corresponding channels fading feature, location-based feature, channel state information (perfect/imperfect), transmission error rate and so on, focusing on this multi-factorial NP-hard problem with high computational complex, therefore, in order to achieve optimal transmission subject to these varied restrictive conditions, we need to transform challenging NP-hard problem to P problem, and propose efficient and low-complexity fundamental CC algorithms.*

**CC with Single Node Selection**

So far, there are mainly two kinds of basic CC core algorithms—single node selection and nodes subsets selection, which are extensively linked with related optimization technologies in all sorts of hybrid scenarios, other various representative
algorithms are also transformation theories based on these two types of methods. The former one includes best node selection, N-th best node selection, partial node selection [7, 8, 12].

*Best node selection: as shown in eq. (1), selecting node with best SNR (Signal to Noise Ratio) / SINR (Signal to Interference and Noise Ratio) in all CC nodes. N-th best node selection: selecting node with N-th SNR/SINR in all CC nodes. Selecting best node with SNR/SINR in partial nodes.

$$SNR = \frac{P_{signal}}{P_{noise}}, \quad SINR = \frac{P_{signal}}{P_{interference} + P_{noise}}$$

where $P_{signal}$ is power of received signal, $P_{interference}$ is power of interference signal, $P_{noise}$ is power of noise.

**CC WITH NODES SUBSETS SELECTION**

Moreover, in contrast to single node selection, nodes subsets selection algorithms are put forward to further improve communication qualities. Generally speaking, nodes subsets selection are better than single node selection, and best node selection algorithm has better performance than other single node selection algorithms, however, for fixed power of CC nodes, random nodes selection algorithms do not absolutely have superiority over best node selection algorithm, some classical subsets selection with better nodes selection and more efficient power allocation like [9-13].

*[9] proposes low-complexity and sub-optimal nodes selection algorithms with corresponding beam-forming weights under constraints of individual relay power, to maximize SNR at the receiver.

*[10] puts forward proactive nodes subsets selection, so that energy efficiency of system would be maximized with low signaling overhead.

*[11] considers minimizing outage probability (OP) at the receiver with semi-distributed nodes subsets selection and power allocation.

*[12] proposes generalized optimal cloud-based nodes subsets pairing algorithm which contains a variety of classical algorithms, raised scheme can reduce OP substantially, compared with other existing algorithms.

*[13] puts forward layers-based optimized mobile nodes subsets algorithms for FD-NOMA to improve transmission rate markedly.

Performance analysis and comparison are listed in Table II. We can observe that multiple nodes subsets schemes are superior to single nodes schemes, and it is more important that proposed CC algorithms should be satisfied with more effective transmission nodes in future.

**TABLE II**

Performance comparison for critical CC algorithms that will be extensively existing in B5G/6G networks

| Algorithms                  | Algorithms description                                                                 | Performance ranking |
|-----------------------------|----------------------------------------------------------------------------------------|---------------------|
| Nodes subsets selection     | $K$-layers based synthesis algorithm (transform NP-hard to P dynamically)               | 1                   |
| [13]                        |                                                                                       |                     |
| Nodes subsets selection     | Intelligent cloud-based dual-hop respective subsets pairing                            | 2                   |
| [12]                        |                                                                                       |                     |
| Nodes subsets selection     | Sub-optimal nodes selection and power allocation in a semi-distributed manner          | 3                   |
| [11]                        |                                                                                       |                     |
| Nodes subsets selection     | Proactive nodes subsets selection to maximum energy-efficiency                          | 4                   |
| [10]                        |                                                                                       |                     |
| Nodes subsets selection     | Low-complexity and sub-optimal nodes selection with corresponding beam-forming weights| 5                   |
| [9]                         |                                                                                       |                     |
| Best node selection         | Best SNR/SINR node selection                                                           | 5                   |
| [7]                         |                                                                                       |                     |
| N-th node selection         | N-th SNR/SINR node selection                                                           | 6                   |
| [12]                        |                                                                                       |                     |
| Partial node selection      | Best SNR/SINR node selection from partial nodes                                         | 6                   |
| [8]                         |                                                                                       |                     |

**CONCLUSIONS AND CHALLENGES**

This paper points that CC technology will be fundamental for Internet of Everything in future B5G/6G hybrid and ubiquitous networks, more importantly, CC ideology is regards as linkage theory for arbitrary two communication nodes, hence, investigating and applying CC technology is very meaningful for developing B5G/6G new communication scenarios and further optimizing transmission performance. We firstly establish hybrid B5G/6G networks topology by integrating various respective B5G/6G networks, such as, CIOT networks, UAVs communications, air-space-ground of integrated networks, underwater acoustic communication and so on, secondly we review critical optimization techniques in CC networks. Then we summarize basic CC core algorithms and compare advantage and disadvantage of these solutions. In general, we believe that development of future communication are closely linked with collaborative ideology, hence we must pay more attention to improvement of communication performance based on CC algorithms in B5G/6G networks.
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