

An Overview on Active Transmission Techniques for Wireless Scalable Networks

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Abstract

Currently, massive data communication and computing pose a severe challenge on existing wireless network architecture, from various aspects such as data rate, latency, energy consumption and pricing. Hence, it is of vital importance to investigate active wireless transmission for wireless networks. To this end, we first overview the data rate of wireless active transmission. We then overview the latency of wireless active transmission, which is particularly important for the applications of monitoring services. We further overview the spectral efficiency of the active transmission, which is particularly important for the battery-limited Internet of Things (IoT) networks. After these overviews, we give several critical challenges on the active transmission, and we finally present feasible solutions to meet these challenges. The work in this paper can serve as an important reference to the wireless networks and IoT networks.

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Keywords: Active transmission, latency, data rate, energy consumption.

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1. Introduction

Currently, massive data communication and computing pose a severe challenge to the existing wireless network architecture [1–4]. At present, the traditional communication network still adopts the communication-centric architecture, which is difficult to support the increasing application demand of massive data computing [5–8]. There is an urgent need to deeply integrate communication and computing, and greatly improve the computing power of the network to support the application of massive data. Computing power has become the infrastructure of national economic development, and computing service has become a new driving force to support the sustained and in-depth development of national digital economy.

In order to support the application demand of massive computing power, researchers have conducted in-depth research on cloud computing, fog computing, and edge computing, proposing a new computing network architecture, the computing force network (CFN) [9–12]. Computing force network deeply integrates computing and network, internally realizes computing endogenesis, externally provides computing services and reshapes the paradigm of the communication network [13–15]. The computing force network significantly improves the utilization of multi-dimensional resources such as communication, storage, and computing of the system through cloud, network and edge computing network collaboration, supports real-time and accurate computing power discovery, flexible dynamic scheduling of services, and ensures the consistency of user experience [16–18]. Wireless transmission is the basic means of computing power discovery and routing in a mobile computing network. Massive data transmission caused by massive computing power convergence brings a heavy burden to the latency and energy consumption of the system, which seriously restricts the development of mobile computing networks. It is urgent to develop new wireless transmission theories and methods that are suitable for mobile computing networks to significantly reduce the latency and energy consumption of massive computing power convergence [19–21].

Wireless transmission is the core technology of the physical layer of the communication network and is also the basis for the convergence of massive computing power in the mobile computing network [22]. Active transmission is equipped with a complete RF circuit on the transceiver of each node of the network, providing a better coverage and transmission performance, and significantly reducing the transmission latency. However, the energy consumption of active transmission is large, the equipment cost is high and the spectrum utilization

rate is low. For this reason, researchers have proposed a new passive wireless transmission technology based on environmental backscattering in recent years, that is, modulating information by reflecting RF signals transmitted by RF sources in the environment, such as base stations and Wi-Fi access points, and realizing passive transmission of information in combination with adjustment of wireless impedance [18,19]. Compared with active transmission, passive transmission significantly reduces the energy consumption and cost of the system and greatly improves the spectrum utilization efficiency of the system. Active and passive cooperative transmission has the great advantage of significantly reducing the latency and energy consumption of wireless transmission of the system. It deeply meets the application requirements of the Internet of Things (IoT) and mobile computing network and has become a hot issue in recent wireless communication research.

2. Recent research progress on active transmission

Active transmission is the traditional working mode of wireless transmission. By providing a complete RF circuit on the transceiver of the network node, it provides a better coverage and transmission performance, and significantly reduces the latency of wireless transmission. However, active wireless transmission also has some disadvantages such as high energy consumption, high equipment cost and low spectrum utilization. In view of the advantages and disadvantages of active wireless transmission, researchers have systematically carried out in-depth research from multiple perspectives based on multiple core performance metrics such as wireless transmission rate, latency and energy consumption, and achieved relatively fruitful research results.

2.1. The study of the rate of active wireless transmission

For the transmission rate of the wireless relay communication system, the relay mode can be flexibly switched between full duplex and half duplex according to the instantaneous state of the wireless channel and self-interference, and the rate of active wireless transmission of the system can be maximized by optimizing the control of transmission power. In the cooperative cognitive network of multi-user wireless charging, non-orthogonal multiple access (NOMA), time division multiplexing (TDMA), and other multi-user access methods can be combined to optimize the allocation of time slots and transmission power to maximize the sum rate of wireless transmission of the primary user. The researchers also analyze the system rate of D2D communication uplink multi-user cellular network and adopt deep reinforcement learning to optimize the power distribution among multiple users and maximize

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the sum rate of active wireless transmission of the system.

2.2. The study of the latency of active wireless transmission

The downlink MIMO NOMA communication system was studied in [23–25] to obtain an upper bound of the active wireless transmission latency of the system. Moreover, consistent latency and reliability among receivers by optimizing transmission power allocation can be obtained among multiple users. For large-scale MIMO communication systems, the latency of active wireless transmission of the system can be minimized by jointly designing the target error rate and the target transmission rate, so as to obtain the basic compromise between the queuing of transmission packets and the re-transmission latency. In addition, for cache-assisted fog access wireless networks, the joint optimization problem of recommendation, cache, and beamforming can also be established from the perspective of active wireless transmission latency, and the cache and spatio-temporal resources can be mixed and optimized on different time scales.

3. Challenges on active wireless transmissions

From the analysis of the above research status, it can be seen that the active transmission shows relatively excellent performance in terms of wireless transmission rate, latency and coverage. Combined with certain resource scheduling, it can further optimize and improve the energy efficiency of the system. Applying active wireless transmission to cloud computing, fog computing, edge computing and other computing network architectures can support the computing of network tasks to a certain extent. In the face of the emerging mobile computing network, especially the convergence demand of the system's massive computing power, active wireless transmission can reduce the latency of system transmission. However, the performance in energy consumption, pricing and other aspects needs to be further improved. Active wireless transmission alone cannot meet the transmission demand of the mobile computing network's massive computing power convergence. It is urgent to explore the internal characteristics of mobile computing network and design new wireless transmission theories and methods that are suitable for mobile computing network.

4. Feasible solutions to the challenges on the active transmission

Based on active transmission and passive transmission, the coexistence strategy of active and passive transmission should be designed to adapt to the mobile

computing network. Specifically, we use d_a , E_a and λ_a to denote the latency, energy consumption and pricing of active transmission, respectively, while use d_p , E_p and λ_p to represent the latency, energy consumption and pricing of passive transmission, respectively. Since the active transmission has the characteristics of long transmission distance, small latency and high energy consumption, while passive transmission has the characteristics of short transmission distance, large latency and low energy consumption, active and passive cooperative transmission provide favorable conditions for low latency and low energy consumption of the system. We should design the coexistence strategy of active and passive transmission suitable for the computing force network according to the specific requirements of computing power convergence. Providing that there are N forcing nodes (D_1, D_2, \dots, D_n) in the force network that can help assist the task calculation of the source node S . In combination with the specific requirements of computing power, pricing, and wireless channel status, one of the best computing power node D_{n^*} can be selected from N computing power nodes to assist the task calculation of the source node S . Since the convergence of computing power S can be realized by active transmission and passive transmission, it is urgent to make comprehensive use of the characteristics of active transmission and passive transmission, which can take full advantages of the active and passive cooperative transmission, and realize the massive convergence of computing power in a mobile computing network.

A feasible scheme is to design the corresponding coexistence strategy of active and passive cooperative transmission for the mobile computing network based on the distributed branch switch-and-stay combining (DSSC) protocol. Specifically, assuming that the active transmission mode is adopted in the previous time slot, the system first checks whether the branch of the active transmission can meet the latency, energy consumption, pricing, and other requirements of the current time slot for the power transmission in the current time slot, given by [26, 27]

$$\psi_{a,J} < \gamma_J \text{ or } \tilde{\psi}_{a,J} < \tilde{\gamma}_J, \quad (1)$$

$$(d_a < \gamma_d) \& (E_a < \gamma_E) \& (\lambda_a < \gamma_\lambda), \quad (2)$$

where $\psi_{a,J}$ and $\tilde{\psi}_{a,J}$ represent the linear combination performance metric and normalized linear combination performance metric under active transmission, respectively. Note that (1) is the performance metric of the linear combination type, while (2) is the performance metric of the logical combination type. As long as the above requirements can be met, the system will always use the branch of active transmission to gather computing power, that is, branch stays. On the contrary, only when the active transmission can no longer meet the multiple requirements of the system transmission,

branch switching will occur. At this time, the branch of passive transmission is enabled to support the convergence of computing power of the system.

Similarly, assuming that the passive transmission mode is adopted in the previous time slot, the system first checks whether the branch of the passive transmission can meet the latency, energy consumption, pricing, and other requirements of the current time slot for the power transmission in the current time slot, which is given by [28, 29]

$$\psi_{p,J} < \gamma_J \text{ or } \tilde{\psi}_{p,J} < \tilde{\gamma}_J, \quad (3)$$

$$(d_p < \gamma_d) \& (E_p < \gamma_E) \& (\lambda_p < \gamma_\lambda), \quad (4)$$

where $\psi_{p,J}$ and $\tilde{\psi}_{p,J}$ represent the linear combination performance metric and normalized linear combination performance metric under passive transmission, respectively. Note that (3) is the performance metric of the linear combination type, while (4) is the performance metric of the logical combination type. As long as the above requirements can be met, the system will always use the branch of passive transmission to gather computing power, that is, branch stays. On the contrary, only when the passive transmission can no longer meet the multiple requirements of the system transmission, branch switching will occur. At this time, the branch of active transmission is enabled to support the convergence of computing power of the system.

The above active and passive cooperative transmission strategy based on the DSSC protocol can significantly reduce the receive complexity of the receiver and the complexity of channel parameter estimation of the system. It is not necessary to estimate the channel parameters of the active and passive branches in each time slot, and the engineering implementation is simple. In addition, from the perspective of long-time multi-slot transmission, the DSSC protocol can make full use of the both branches of active and passive transmission to support the convergence of the computing power of the system.

In addition to the coexistence strategy of active and passive cooperative transmission based on DSSC protocol, we should also deeply consider the internal requirements of tasks such as computing power and pricing, and design the coexistence strategy of other forms of active and passive cooperative transmission, to make full use of the respective characteristics of active and passive transmission, give play to the inherent advantages of active and passive cooperative transmission, and effectively support the application demand of massive computing power convergence of the system.

Moreover, a spatio-temporal transceiver can be set at the node of the mobile computing network to mine the spatio-temporal transmission resources of

the system. In the mobile force network, the number of antennas (elements) at the task node, tag node, and computing power node is represented by M_1 , M_2 , and M_3 , respectively. The existence of multiple antennas or multiple elements makes it possible to mine the spatial resources of the system. In addition, due to the movement of nodes, the wireless transmission channel will show the characteristics of changing with time, which provides an important possibility for mining the temporal resources of the system and then designing the corresponding active and passive transmission methods. Therefore, it is necessary to design a spatio-temporal transceiver at the nodes of the mobile computing network, make full use of the spatio-temporal transmission characteristics of the system, and design corresponding active and passive cooperative transmission methods.

The existing research have shown that the fractional transverse filter (FTF) is a feasible choice for the spatio-temporal transceiver of the mobile computing network. FTF is simple in structure, and easy for engineering implementation and system optimization. It can effectively mine the spatial and temporal resources of wireless transmission of the system, improving the performance of the wireless transmission significantly, and assisting the convergence of computing power of the computing force network effectively. In addition to the feasible option of FTF, we can also consider other types of spatio-temporal transceivers to make full use of the spatio-temporal transmission characteristics of the considered system.

After determining the type of spatio-temporal transceiver, it is necessary to further determine the design criteria of the spatio-temporal transceiver to solve the transceiving coefficient of the spatio-temporal transceiver. Specifically, the spatio-temporal transmission coefficients of the task node, the tag node, and the computing force node at the time t are represented by $\mathbf{W}_1(t)$, $\mathbf{W}_2(t)$, and $\mathbf{W}_3(t)$, respectively. For the performance metric of linear combination type, the design of the spatio-temporal transceiver can be realized by adjusting $\mathbf{W}_1(t)$, $\mathbf{W}_2(t)$, and $\mathbf{W}_3(t)$ to minimize the cost $\psi_J(t)$, given by

$$\begin{aligned} \arg \min_{\{\mathbf{W}_1(t), \mathbf{W}_2(t), \mathbf{W}_3(t)\}} \psi_J(t) \\ \text{s.t. } R(t) \geq \gamma_R, \\ f_c(t) \geq \gamma_f. \end{aligned} \quad (5)$$

Similarly, for the normalized linear combination performance metric, the design of the spatio-temporal transceiver can be realized by adjusting $\mathbf{W}_1(t)$, $\mathbf{W}_2(t)$, and $\mathbf{W}_3(t)$ and minimizing the normalization cost of the

time, given by

$$\begin{aligned} & \arg \min_{\{\mathbf{W}_1(t), \mathbf{W}_2(t), \mathbf{W}_3(t)\}} \tilde{\psi}_J(t) \\ & \text{s.t. } R(t) \geq \gamma_R, \\ & f_c(t) \geq \gamma_f. \end{aligned} \quad (6)$$

For the performance metric of logical combination type, $\mathbf{W}_1(t)$, $\mathbf{W}_2(t)$, and $\mathbf{W}_3(t)$ will affect the latency $d(t)$, energy consumption $E(t)$, and rate of wireless transmission of the system $R(t)$. Therefore, a feasible design criterion is to maximize the end-to-end signal-to-noise ratio of the wireless transmission of the system by

$$\arg \min_{\{\mathbf{W}_1(t), \mathbf{W}_2(t), \mathbf{W}_3(t)\}} \text{SNR}_{e2e}(t). \quad (7)$$

By maximizing the end-to-end signal-to-noise ratio, the wireless transmission rate of the system can be effectively improved, and the transmission latency and energy consumption can be reduced. In addition to the above design criteria, we can also comprehensively consider other design criteria to solve $\mathbf{W}_1(t)$, $\mathbf{W}_2(t)$, $\mathbf{W}_3(t)$, realizing the design of the wireless transmission transceivers, supporting the application requirements of mobile computing network computing convergence.

In further, based on Lyapunov and convex optimization algorithms, the coefficients of spatio-temporal transceivers of network nodes can be solved, and the method design of active-passive cooperative transmission of the system is realized. The existing researches have shown that the Lyapunov algorithm can effectively solve the time-varying network parameters by modeling the time-varying parameters into queues to control the change of queue state, which provides an important way to solve the spatio-temporal transmission and reception coefficients of active and passive cooperative transmission of mobile computing network nodes. For N computing power nodes, $\mathbf{Q}_h(t)$, $\mathbf{Q}_c(t)$, $\mathbf{Q}_\lambda(t)$, $\mathbf{Q}_d(t)$, and $\mathbf{Q}_E(t)$ can be used to represent the channel parameter queue, computing power queue, pricing queue, latency queue, and energy consumption queue of the system, respectively. Then, the channel parameter queue $\mathbf{Q}_h(t)$ is represented as

$$\mathbf{Q}_h(t) = [Q_{h,1}(t), Q_{h,2}(t), \dots, Q_{h,N}(t)]. \quad (8)$$

The other queues $\mathbf{Q}_c(t)$, $\mathbf{Q}_\lambda(t)$, $\mathbf{Q}_d(t)$, and $\mathbf{Q}_E(t)$ are similarly defined. From the aboven given queues, the construction of computing communication integrated queue $\mathbf{Q}_J(t)$ is wirtten as

$$\mathbf{Q}_J(t) = [\mathbf{Q}_h(t), \mathbf{Q}_c(t), \mathbf{Q}_\lambda(t), \mathbf{Q}_d(t), \mathbf{Q}_E(t)]. \quad (9)$$

From (9), the Lyapunov quadratic function $\text{Ly}(\mathbf{Q}_J(t))$ and the Lyapunov conditional drift factor $\Delta(\mathbf{Q}_J(t))$ can

be obtained by

$$\begin{aligned} \text{Ly}(\mathbf{Q}_J(t)) &= \frac{1}{2} \mathbf{Q}_J^2(t) \\ &= \frac{1}{2} \mathbf{Q}_h^2(t) + \frac{\mu_1}{2} \mathbf{Q}_c^2(t) + \frac{\mu_2}{2} \mathbf{Q}_\lambda^2(t) + \frac{\mu_3}{2} \mathbf{Q}_d^2(t) + \frac{\mu_4}{2} \mathbf{Q}_E^2(t), \end{aligned} \quad (10)$$

$$\Delta(\mathbf{Q}_J(t)) = E[\text{Ly}(\mathbf{Q}_J(t+1)) - \text{Ly}(\mathbf{Q}_J(t)) | \text{Ly}(\mathbf{Q}_J(t))], \quad (11)$$

where μ_1 , μ_2 , μ_3 , and μ_4 are non-negative variables, which are used to control the weights of various elements in the system. Notation $E(\cdot)$ is the expectation operation, i.e. measuring the updated value of the quadratic function under the current quadratic function condition. From (10) and (11), we can establish the correlation with the optimization criteria (5), (6), and (7) to obtain the Lyapunov drift plus penalty function. Moreover, we can analyse the upper limit of Lyapunov drift plus penalty function, and combine with the convex optimization and other algorithms to minimize the upper limit, the spatio-temporal coefficients $\mathbf{W}_1(t)$, $\mathbf{W}_2(t)$ and $\mathbf{W}_3(t)$. In this way, the method design of active and passive cooperative transmission of a mobile computing network is realized.

5. Conclusions

Currently, massive data communication and computing pose a severe challenge to the existing wireless network architecture, from the various aspects such as data rate, latency, energy consumption and pricing. Hence, it is of vital importance to investigate the passive and active wireless transmission for the wireless networks. To this end, we firstly overview the data rate of wireless active transmission. We then overview the latency of wireless active transmission, which is particularly important for the monitoring services. We further over the spectral efficiency of the active transmission, which is particularly important for the battery-limited Internet of Things (IoT) networks. After these overviews, we give several critical challenges on the active transmission, and we finally give some feasible solutions to meet these challenges. The work in this paper can provide an important reference for the wireless networks and IoT networks.

5.1. Data Availability Statement

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