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**Joint Connection Modes, Uplink Paths and Computational Tasks Assignment for Unmanned Mining Vehicles’ Energy Saving in Mobile Edge Computing Networks**

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**ABSTRACT** At present, most unmanned mining vehicles (UMVs) adopt batteries to meet the requirementsof low power consumption in driving control systems, and saving energy is the key to increase the working time and production efficiency. Mobile edge computing (MEC) is an effective technology that can improve the driving performance, whereas reduces the power consumption caused by the UMV’s CPU. However, sending more offloading tasks to MEC servers means higher wireless channel transmission power, and especially in mining areas, where the communication quality of wireless channels are easily deteriorated by dust, rocks and ravines. To solve this contradiction, this paper firstly analyzes the UMVs’ consumption of computational power and communicational power based on the proposed MEC architecture. Then, considering that flexible connection methods can reduce the end-to-end delay of offloading tasks and improve the use efficiency of link resources, a joint connection modes, uplink paths and computational tasks assignment method is proposed to reduce the power consumption under a strict delay constraint. Furthermore, a novel algorithm is presented to obtain the optimal parameters. Finally, through a simulation experiment, the effectiveness of this method in reducing the power consumption compared with the shortest path method is proved.

**INDEX TERMS** V2X communication, mobile edge computing (MEC), unmanned mining vehicles(UMVs), power consumption.

**I. INTRODUCTION**

With the rapid development of intelligent driving technology, unmanned mining vehicle (UMV) has become an effective tool that can improve production efficiency and reduce labor costs in mining areas. Some studies have pointed out that 7 UMVs can replace at least 9 manned vehicles with the same workload and the profit rate including labor cost savings is increased by 49% [1-3]. However, the mining area is different from the traditional unmanned vehicle environment, having the characteristics of poor road conditions, random obstacles and no obvious traffic sign, which can cause vehicular sensors difficult to detect the environment clearly [4]. Due to the application of vehicle-to-everything communication (V2X), mobile edge computing (MEC) [5] has become a promising technology

that enables UMVs to access computation and storage services from edge computing servers (ECSs) located at road side units (RSUs) or base stations (BSs). It can also compensate the disadvantages of the sensor devices and significantly improve the UMVs’ performance by sharing the information among the local roads, vehicles and pedestrians with RSUs [6].

Typically, each vehicle can be equipped with a cellular network interface and an IEEE 802.11p network interface [7], and there are two link modes for UMVs connected to the ECS in mining area: the direct connection mode, where UMVs can be directly connected to ECSs and exchange data with the RSUs through the vehicle-to-infrastructure (V2I) links [8]; and the V2V relay mode, where UMVs are indirectly connected to ECS through the vehicle-to-vehicle

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(V2V) links to realize the relay of multiple vehicles. Through these two link modes, UMVs will be more flexible to send the offloading tasks to ECS, which can effectively reduce the operating pressure of the UMVs’ computers and increase the transmission efficiency of task data. Currently, UMVs are widely used in mining areas, and the tasks they are engaged in is complicated, causing a huge demand for resources, including the time, storage capacity, bandwidth, electrical energy and so on. To improve the utilization efficiency of resources, researchers have proposed some relational optimization methods applied in vehicular MEC networks, including the increasing the task offloading gains, reducing the task completion time and reducing energy consumption for ECSs [9]-[11].

In the mining area, UMVs’ driving route and driving area are relatively fixed, and their number is limited by the size of the mining site. Comparing with the traditional unmanned autonomous vehicles, the stable network architecture and network requirements make the resources management of V2X networks and ECSs simpler. Therefore, the above methods aiming at improving the utilization of computing resources and reducing the delay can be sufficient for the use of UMVs. However, these methods are only for the entire network or ECSs, and they cannot effectively reduce the power consumption of UMV itself. Now, most UMVs adopt batteries to meet the power consumption requirements of driving control systems, and even several UMVs directly use electrical energy as their driving force. To improve production efficiency in the mining area, UMVs need to work as long as possible, which means that saving energy becomes more important

1. The UMV’s energy consumption in MEC networks consists of two parts: computational power consumption and communicational power consumption. Because UMV’s CPU occupies a large part of the energy consumption, uploading more offloading tasks to ECSs can significantly reduce the UMV’s computational power consumption, but it can cause a higher wireless channel transmission power. Besides, different connection modes and different uplink paths can result in different communicational power consumption, and the difference will be more obvious when the quality of wireless channels become worse due to the influence of dust, rocks and ravines in mining areas.

Therefore, to resolve the contradiction between

computational consumption and communicational consumption, a joint connection modes, uplink paths and computational tasks assignment method is proposed to reduce the power consumption under a delay constraint. Our main contributions are as follows.

 A V2X communication architecture adopted MEC networks is proposed, and based on this architecture, UMV’s computational power consumption and communicational power consumption are analyzed.

 A novel method that comprehensively considers the factors including connection modes, uplink paths,

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communicational loads, and computational tasks is proposed to achieve the minimum power consumption for UMV in the mining area, and a traversal algorithm is presented to calculate the optimal parameters of this method.

* A simulation experiment is designed to prove the effectiveness of the proposed method, and the total power consumption is evaluated by comparing the three different methods: the proposed method, the optimal tasks assignment method with the shortest

path and the optimal tasks assignment method with the fixed path.

The rest of the paper is organized as follows. A literature survey is presented in Section II. In Section III, UMV’s computational power consumption and communicational power consumption are analyzed in detail. Next, the solution for achieving minimum power consumption is introduced in Section IV. In Section V, performance evaluation results are presented, and conclusions are drawn in Section VI.

**II. RELATED WORKS**

MEC technology has been proposed to be applied in vehicular networks for several years, which can significantly improve the performance of autonomous vehicles, connected vehicles, and the internet of vehicles (IoV). Zhang et al. [13] proposed the mobile-edge cloud-enabled vehicular networks using MEC servers, whose main role is to accomplish the computation tasks between remote clouds and local vehicular terminals. MEC servers receive the task input messages from vehicles and then predict the processing time to finish the offloading tasks. Meanwhile, Liu et al. [14] proposed an application-specific concept for scalable software-defined networking (SDN)-enabled vehicular networking, combined with MEC to provide reliable communication services over a heterogeneous V2X communication, which can reduce the round-trip time for packet transmission. Moreover, Ning et al. [15] presented a NOMA-based scheme for vehicular networks enabled by MEC, which is an early attempt to offload network traffic by comprehensively leveraging the technologies of spectrum reuse and high-efficiency computing. Due to the high computational complexity of the formulated problem, a heuristic method is designed from the aspects of offloading decision, channel assignment, and power control. Furthermore, He et al. [16] presented an integrated framework that can enable dynamic orchestration of networking, caching, and computing resources to improve the performance of next generation vehicular networks, and proposed a resource allocation strategy using a novel deep reinforcement learning approach to resolve the joint optimization problem, where the gains of networking, caching and computing are taken into consideration.

Now, more and more autonomous vehicles are traveling on roads, which cause the performance requirements of

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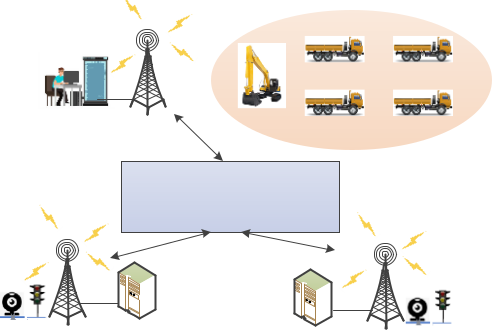
MEC vehicular networks to become higher and higher based on the above network architectures. Compared with the autonomous vehicles in urban areas, UMVs not only need to optimize resources to achieve minimum delay and to meet quality of service (QoS) requirements of different driving tasks, but also need to consider how to reduce the power consumption. Ding et al. [17] proposed an optimal power and time allocation method to establish the conditions for determining whether the conventional orthogonal multiple access (OMA), pure non-orthogonal multiple access (NOMA) or hybrid NOMA should be used for MEC offloading. Tran et al. [18] presented a joint task offloading and resource allocation method adopted for multi-server MEC networks, which can maximize the task offloading gains and reduce the task completion time and ECSs’ energy consumption. Ren et al. [19] proposed a joint communication and computation resource allocation solution to improve edge cloud efficiency with limited communication and computation capacities and achieve a better delay performance. Meanwhile, Zhang et al. [20] proposed a software-defined reconfigurable passive optical network (PON) architecture to optimize the bandwidth resource allocation based on the expected traffic demands, which can improve the throughput and real-time performance of the link between BS and ECS. Additionally, Almohammedi et al. [21] proposed an adaptive multi-channel assignment and coordination scheme that ensures an efficient and reliable quality of service (QoS) of the V2V links under different traffic flows and improves the time diversity among vehicles based on the traffic conditions.

In addition to the above resources optimization methods, adjusting the transmission paths of offloading tasks is also an effective method to reduce the transmission power and balance the linking loads. The methods of reducing power consumption by planning transmission paths have also been applied to unmanned aerial vehicles (UAVs), because UAVs are only used to obtain ground dynamic subsidence basin data in mining area in a short time with the limited batteries and highly mobility [22]. To overcome the shortcoming, Mukherjee et al. [23] proposed a method that focused on selecting the most optimal multi-hop path for UAVs, which can survive the duration of the data offload between the source and a target UAV. Furthermore, Jeong et al. [24] minimized the UAV energy budget by jointly optimizing the UAV trajectory and the bit allocation in uplink and downlink under the condition of guaranteeing the users’ quality of service. Similar to UAVs, UMVs’ link paths are also very flexible, but the UMV supports more connection modes, and the amount of data transmitted is much larger, which means that the method of reducing UMV’s power consumption is much more complicated. Therefore, this paper will consider more factors including connection modes, uplink paths, communicational loads and computational tasks.

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1. **SYSTEM MODEL AND PROBLEM FORMULATION**

The architecture of UMVs’ network with MEC servers in the mining area is presented and the illustrated case depicted in Figure 1 is used as an example. In this network, UMVs are distributed in the mining area according to engineering tasks, and RSUs are installed in places with poor traffic conditions to provide a good driving vision for UMVs. Each UMV is equipped with a cellular network interface and an IEEE 802.11p network interface. Through these two interfaces, UMVs send offloading tasks to ECS located in BS and RSUs, and receive surrounding information and computational results from ECSs. Since there will not be too many UMVs in the entire mining area for the size limitation and the production safety, and there are no other competitors, the resources of ECSs located in the central control room and RSUs are sufficient for all UMVs. Furthermore, for managing the network resources and computing resources more conveniently and flexibly, the SDN controller [25] and the Network Function Virtualization (NFV) [26] hypervisor are applied in this network. Based on this network architecture, the following analyzes the power consumption in two aspects.



Central Control Room

BS UMVs

SDN Controller

NFV Hypervisor

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RSU | MEC Server | MEC Server | RSU |  |
|  |  |  |



|  |  |  |
| --- | --- | --- |
| UMVs | UMVs |  |
|  |  |

**FIGURE 1. The architecture of UMVs’ network with MEC servers in the mining area**

***A． COMPUTATIONAL MODEL***

We assume that all UMVs have similar tasks and each UMV’s tasks can be characterized as *T*  {*ck*, *d* *k*, *qk*}, *k*  *S* , where *c* *k* denotes the size of the task; *d* *k* denotes the tolerance delay of finishing the task; *qk* denotes the required number of CPU cycles that is needed to complete the task; and *S* is the number of tasks. In the MEC network, a simple task cannot be divided, either it is calculated locally or it is transferred to the edge node for calculation. Therefore, the efficiency of the task execution is determined by the performance of the UMV’s computer and the ECSs. We use *S* *l* to represent the set of tasks processed in the UMV’s computer and *S* *e* to represent the

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| set of tasks processed in the ECSs, so that by assigning *S* *l* | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  | *N* | | |  | *Ri* | |  |  |  |  | *N* | | |  | * ci* | |  |  |  |  |
| and *S* *e* , different computation task models can be obtained. | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  | *PC* | | |  | (2 | *B i* | 1)  | | |  | | (2 | *Bi i* |  | 1) | | (5) |  |
|  |  | 2 | | | |  | 2 | | |  |
| The CPU of a UMV is the primary engine for local | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  | *i**S e* |  |  | *h* |  |  |  |  |  |  |  | *i**S e* | | | *h* |  |  |  |  |  |  |  |  |
| computation, and the computation performance is | | | | | | | | | | | | | | | | | | | | | | | | | | | where ** *i* | | is | the upload latency of each task, and | | | | | | | | | | | | | | | | | | | | *Bi* is the | |  |
| determined by the CPU clock speed | | | | | | | | | | | | | | | | | | | | | *f l* .So, the execution | | | | | | available bandwidth of each task. | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
| time can be obtained as follows. | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  | Through the above analysis, we can find that the | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  ( *ci* *qi*) | | | | | | | | |  |  |  |  |  |  |  | transmission | | | power |  |  | is | | | determined | | | | | |  |  | by | | the | | | amount | | of |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | offloading tasks. Considering | | | | | | | | | | | | that more | | | | | | | offloading tasks | | | | | |  |
|  |  |  |  |  |  |  |  | * L* |  |  | *i**S l* |  |  |  |  |  |  |  |  |  |  |  |  |  |  | (1) |  |
|  |  |  |  |  |  |  |  |  | *f l* |  |  |  |  |  |  |  |  |  |  |  |  |  |  | will bring less computational power consumption but | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| and then computational energy consumption in UMV is | | | | | | | | | | | | | | | | | | | | | | | | | |  | higher communicational power consumption, the | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  | *P L*  * L*  * ci q i f l*2 | | | | | | | | | | | | |  |  |  |  |  | (2) | assignment of computational tasks is an effective way to | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  | *i**S l* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | achieve minimum power consumption for UMVs. Apart | | | | | | | | | | | | | | | | | | | | | | | | |  |
| where ** is a constant related to the hardware architecture. | | | | | | | | | | | | | | | | | | | | | | | | | | | from this, the different connection modes and uplink paths | | | | | | | | | | | | | | | | | | | | | | | | |  |
| Because the computational ability of UMV’s CPU cannot | | | | | | | | | | | | | | | | | | | | | | | | | | | have an important impact on the loads of the link and the | | | | | | | | | | | | | | | | | | | | | | | | |  |
| signal-to-noise ratio (SNR) of the wireless channel, which | | | | | | | | | | | | | | | | | | | | | | | | |  |
| be | changed | | | | | | by | users, reducing | | | | | | | | | | | | the | |  | number of | | tasks | |  |
|  | can affect the real-time performance of the task execution. | | | | | | | | | | | | | | | | | | | | | | | | |  |
| computed in UMV’s CPU is the only effective approach | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| To ensure that each task is completed within a specified | | | | | | | | | | | | | | | | | | | | | | | | |  |
| according to the above formulas. However, the increase of | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| time, | it is necessary to | | | | | | | | improve the transmission rate by | | | | | | | | | | | | | | | |  |
| offloading tasks | | | | | | | | can |  | increase the | | | | | | | | | | | transmission | | | | power | |  |
|  | adjusting the transmission power. | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
| consumption. | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| ***B． COMMUNICATIONAL MODEL*** | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  | **IV. CONNECTION MODES, UPLINK PATHS AND** | | | | | | | | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  |  | **COMPUTATIONAL TASKS ASSIGNMENT** | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |
| In MEC networks, the V2I links and the V2V links are all | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |
| In this section, we firstly analyze the impact of different | | | | | | | | | | | | | | | | | | | | | | | | |  |
| connected by radio waves, and we stipulate that all wireless | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| path | combinations | | |  |  |  |  |  | and | | | connection | | | | | | | | modes | | | | on |  |
| links have the same gain and noise. There are not too many | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |
| communicational power consumption, and then we propose | | | | | | | | | | | | | | | | | | | | | | | | |  |
| UMVs in the mining area and there are no other users, the | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| an algorithm to achieve the optimal connection modes, path | | | | | | | | | | | | | | | | | | | | | | | | |  |
| allocated spectrum of wireless signals is sufficient for all | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| combinations and computational tasks assignment. | | | | | | | | | | | | | | | | | | | | | | | |  |  |
| UMVs. So through OMA technology, interference between | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| different | | | | | | wireless channels can be ignored. According to | | | | | | | | | | | | | | | | | | | | | ***A.*** | ***PATH LOSS AND CONNECTION MODES*** | | | | | | | | | | | | | | | | | | | | |  |  |  |  |
| Shannon's theorem [27], the | | | | | | | | | | | | uplink | | | | | | | | | transmission rate | | | | | of |  |  |  |  |
| Different | | connection | |  |  | modes | | | | | | and | | transmission paths | | | | | | | | | | can |  |
| UMV can be expressed as | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | result in different path loss, which is the main factor that | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 *PC* | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | *R*  *B*log2(1 | | | | |  |  | *h* | |  | ) |  |  |  |  | (3) | can affect the SNR in the wireless network, so each UMV | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | transmission power becomes: | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | *N* | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | | | |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |
| where | |  | *h* |  | 2 is the channel gain; *N* denotes the channel noise; | | | | | | | | | | | | | | | | | | | | | |  |  | *PT* min | |  | *P*max | | | |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | | | |  |  |  |  |  |  |  |  |  | |  |  |  |  |  | (6) |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *P C* | represents the transmitting channel power of UMV and | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  *P G*  *PL*  *Pother*  | | | | | | | | | | | | | | |  |  |  |  |  |  |  |
| *B* is the channel bandwidth. According to [5], the | | | | | | | | | | | | | | | | | | | | | | | | | | | where *P* max is the maximum power that the UMV’s | | | | | | | | | | | | | | | | | | | | | | | | |  |
| execution time ** *E* of the offloading tasks contains upload | | | | | | | | | | | | | | | | | | | | | | | | | | | transmission antenna can provide; | | | | | | | | | | | | | | *P G* is the channel goal | | | | | | | | | | |  |
| latency ** *T* and computation latency ** *C* . | | | | | | | | | | | | | | | | | | | | | | | | |  |  | power, and it satisfies *P* *G* 10log10 *PC* ; and | | | | | | | | | | | | | | | | | | | | *P other* | | | indicates | |  |
|  |  |  |  |  |  |  | *E**T**C* | | | | |  | * ci* | | | | | |  |   | |  | (*ci* *qi*) |  |  | (4) | the other consumption mainly caused by the electrical loss. | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  | *Ri* | | | | |  | * f e* | |  | Because | | *P other* has very little effect on transmission power, | | | | | | | | | | | | | | | | | | | | | | |  |
| where ** | | | | | |  |  |  |  |  | *i**S e* |  |  |  | *i**S e* | |  |  |  |  |
| is the utilization efficiency of the wireless channel | | | | | | | | | | | | | | | | | | | | | it can be ignored. In free space, if the transmitting antenna | | | | | | | | | | | | | | | | | | | | | | | | |  |
| capacity; | | | | | | *Ri* | is the average transmission rate of task *i*; ** is | | | | | | | | | | | | | | | | | | | | radiates spherical electromagnetic waves, the path loss is | | | | | | | | | | | | | | | | | | | | | | | | |  |
| the computing ability that depends on the available resource; | | | | | | | | | | | | | | | | | | | | | | | | | | | defined as follows: | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | *P r* | |  |  |  |  |  |  |  | *G r G t v*2 | | | | | | |  |  |  |  |
| and | *f e* | | | | | denotes | | the | clock speed | | | | | | | | | | | of | | ECS. Because | | | | the |  | *PL*  10lg( | | | | | )  10lg( | | | | |  |  |  | ) | (7) |  |
|  |  | |  | (4** )2 *f* *c*2*d* *vb*23*L* *f* | | | | | | | | |  |
| resources of ECS are sufficient for UMVs, the computation | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  | *Pt* | | |  |  |  |  |  |  |  |  |
| delay in ECS can be assumed to be fixed and will not | | | | | | | | | | | | | | | | | | | | | | | | | | | where *Pt* | | is the power at the transmitting point; | | | | | | | | | | | | | | | | | | | | | *P r* is the | |  |
| change with the increase of offloading tasks. Once the | | | | | | | | | | | | | | | | | | | | | | | | | | | power at the receiving point; | | | | | | | | | | | | *L f* | | is the loss factor of the | | | | | | | | | | |  |
| tolerable delay of each task is determined, we can calculate | | | | | | | | | | | | | | | | | | | | | | | | | | | system; *G* *t* and *G* *r* are the gains of the transmitting and | | | | | | | | | | | | | | | | | | | | | | | | |  |
| the transmission rate of each task by the above formula, and | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| receiving antennas, respectively; *f* *c* | | | | | | | | | | | | | | | is the center frequency | | | | | | | | | |  |
| then determine | | | | | | | | the transmitting | | | | | | | | | | | | channel power by | | | | | | the |  |
| of the signal; *v* is the velocity of the electromagnetic wave; | | | | | | | | | | | | | | | | | | | | | | | | |  |
| calculated rate. | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | and | *d vb*3 | is | the distance between | | | | | | | | | | | | the | | | | transmitting | | | | | and |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | receiving | | antennas. | |  |  | Considering | | | | | | | | that most | | | | | | | | UMVs | | are |  |
| VOLUME XX, 2020 | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |

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2 *D* *ij*

*2 D ij*

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**

traveling in mining areas where the wireless signal of RSUs and BSs can be fully covered and there is less obstruction between every two vehicles, a line-of-sight (LOS) and a none-line-of-sight (NLOS) propagation model for frequencies from 0.5 to 100 GHz proved in [28] and [29] are used to analyze the path loss.

power of all UMVs can be obtained by:

1.  [*T* *V* ( *k* )( *P* *G*1( *k* )  *PL* *k* ( *k* 1))  *T* *D* ( *k* )( *P* *G* 2( *k* )  *PL* *kk* )]*M*
2. 1

(10)

where *T* *V* and *T* *D* are the uplink transmission times of the

V2V relay mode and the direct connection mode,

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 22log 10(*l* *ij*)  20 log10( *f* *c*)  28 | | | | 10 *m*  *l* |  |
|  |  |  |  |  |  |
| *PL LOS*  40log10(*l ij*)20 log10( *f c*)28 | | | | *d BP*  *l* |  |
|  | 2 | 2 | ] |  |
|  | 9log 10[*d* *BP*  ( *h* *B*  *hV* ) | |  |  |

and

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | *PL LOS* | | | |  |  |  |  |
| *PLNLOS* |  max |  | 39.08log | 10 | ( | *l ij* | )  13.54  |  | 10 *m*  | *l* |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  20log10( *f* *c*)  0.6( *hV* 1.5) | | | | | |  |  |  |  |

*ij*2 *D*  *d BP*

* 5*km*

(8)

* 5 *km*

(9)

respectively; *PG*1 is the channel goal power in V2V link and *P G* 2is the channel goal power in V2I link; *PLk* ( *k* 1)is thepath loss between UMV *k* and UMV *k*+1, and *PL* *kk* denotes the path loss between UMV *k* and RSU ( or BS). Considering that the influence of connection modes and uplink paths is complicated, we divide the transmission power consumption of each UMV into two parts: the power consumption of direct connection mode *P* *D* and the power consumption of V2V relay mode *PV* :

*R*1( *k* )

where *l* *ij* is the distance between UMV *i* and UMV *j* and it refers the distance between UMV *i* and a RSU (or BS)

when *i*  *j* ; *l* *ij*2*D* represents the two-dimensional distance

of *l* *ij* ; *h* *B* is the height of RSU (or BS) and it satisfies

10 *m*  *hB*  150 *m* ; *hv* denotes the height of the UMV’s antenna and it should satisfy 1.5 *m*  *hV*  22.5 *m* ; *d* *BP* represents the breaking point of the path loss model, and it

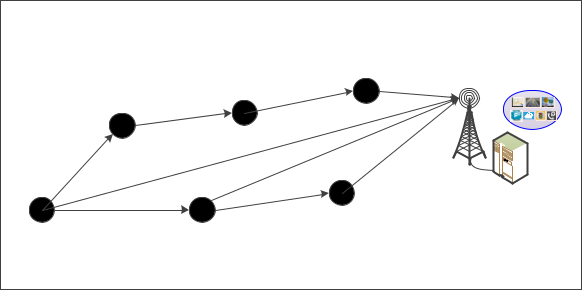
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| satisfies *d* *BP*  4*h* *B* *hV* *f* *c* / *v* . In | | most | V2X communication | |
| networks, the carrier | center | | frequency | satisfies |
| 1 *GHz*  *f* *c*  100 *GHz* , | and | the | interval of | RSUs is |

generally not more than 1 kilometer according to [9].

Therefore, by analyzed the (8) and (9), the path loss in the

mining area can be presented as

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *PL* 22log10(*l ij*)20log10( *f c*)28. | | |  |  |  |  |
|  | Vk+2 | C1+… | Vk+3 | C1+… |  |  |
| Vk+1 | +C3 |  | +C4 |  |  |
| C1+C2 |  |  |  |  |  |
| C1 | C1 | C1+C2 | C1+… | |  |  |
|  |  | MEC |  |
|  |  |  | +C3 | |  |
|  |  |  | Server |  |
| C1 |  | C1+C2 Vk+2 | |  |  |
| Vk+1 |  |  |  |
| Vk |  |  |  |  |  |

**

**FIGURE 2. An example of UMVs’ links in the MEC network**

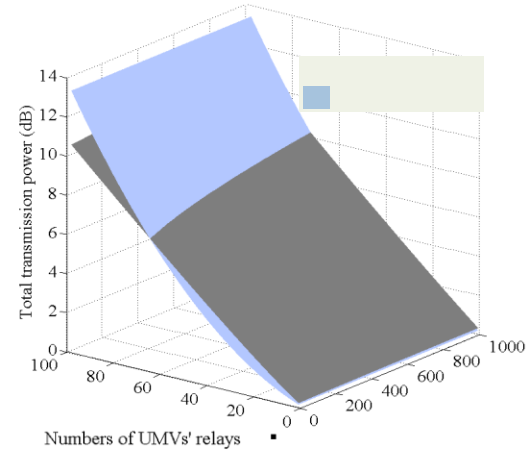
Each UMV has two link modes connected to the ECS including the direct connection mode and the V2V relay mode, which make links of the V2X more complicated. Figure 2 presents a scenario where UMVs adopt mixed modes to connect to the ECS, and we can find that different link modes will cause different transmission distances and different link loads accumulated by multiple vehicle relays. To determine the power consumption caused by different connection modes and link paths, we assume that there are *M* UMVs in the mining area, and then the transmission

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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *P D*  *T D*( *k* )(10log10( | | | |  |  | *N* | | |  |  |  |  |  |  |  |  |  |
|  | (2 | | *B*1 |  | 1))  | (11) |  |
|  |  | *h* | | |  | 2 |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 22log10(*l* *kk* )  20log10( *fc* )  28 | | | | | | | | | | | | | | | |  |  |
|  |  |  | *N* | | | | |  |  |  |  | *R* 2( *k* ) | |  |  |  |  |
| *P V*  *T V* ( *k* )(10log10( |  |  |  | | (2 | |  | *B* 2 | 1))  | | (12) |  |
|  |  | *h* | | | |  | 2 | |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

22log10(*l* *k* ( *K* 1))  20log10( *fc* )  28

According to above formulas, there are many factors that can affect the transmission power consumption, including the transmission time, the NSR, the channel bandwidth, the transmission rate and the transmission distance. To understand the difference between these two modes more clearly, a numerical analysis method is used to analyze the power consumption under different conditions. The following analyzes one of the network scenarios whose main parameters can refer to Table II. The numbers of UMVs and signal coverage radius of the RSU can affect the allocation of network resources in the mining area, the UMVs’ linking states and transmission distances. Therefore, through these two parameters, we can more fully understand the UMV’s performance.

**

Direct connection mode

V2V relay mode

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1 |  | 50 | Signal coverage radius |  |
|  |  |  | of the RSU (m) |  |
|  |  |  |  |

**FIGURE 3. The total transmission power of the direct connection mode and V2V relay mode.**

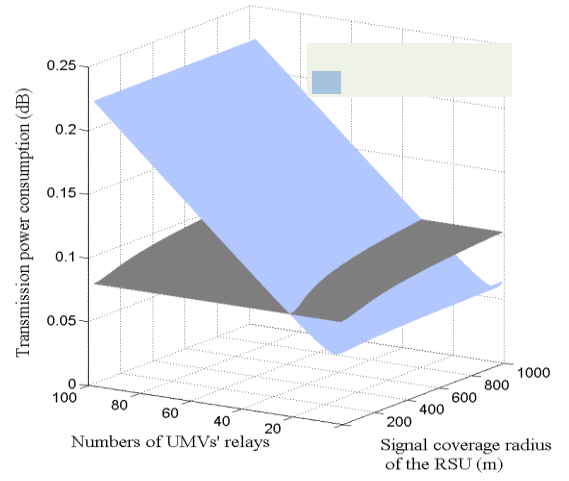
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Direct connection mode



V2V relay mode

1 50

**FIGURE 4. The transmission power of a UMV at the signal edge in terms of the direct connection mode and V2V relay mode.**

Figure 3 and 4 present the total transmission power consumption of all UMVs in the mining area and the transmission power consumption of a UMV at the signal edge under different numbers of UMVs’ relays and different signal coverage radius of the RSU, respectively. Compared with the direct connection mode, the V2V relay mode has a shorter average transmission distance by sharing a common link path but needs a higher transmission rate due to the increase of task data accumulated through multiple relays. Consequently, when the number of UMVs’ relays is small, the total power consumption of V2V relay mode is less than the total power consumption of direct connection mode, but as the number of UMVs’ relays increases, the advantages of V2V relay mode will become less obvious. The same phenomenon will happen to a UMV at the signal edge of the RSU where the distance between the UMVs and the ECS is the longest, and the number of UMVs that can be switched to relay the offloading tasks is also the largest. After relaying through a small number of UMVs, the transmission power consumption of V2V relay mode will be less than direct connection mode, but with the increase of relay UMVs, the power consumption of V2V relay mode will become higher than direct connection mode

Based on the previous analysis, it can be seen that a single connection mode can only meet the minimum transmission power requirement in certain special scenarios. In practice, the number, the location and the interval of UMVs in the signal area covered by different RSUs will change according to the engineering task. Therefore, for different network states, a flexible connection mode that combines the direct connection mode and the V2V relay mode and provides optimal link paths for each offloading task is proposed to ensure the minimum output power of UMVs. Besides, the assignments of computational tasks are also considered to achieve the minimum computational power consumption.

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1. ***MODES, PATHs AND TASKS ASSIGNMENT***

In the mining area, for production safety, UMV’s driving will not be too fast, so we assume that the relative position change caused by vehicular movement in a short period can be ignored. Moreover, due to the continuity of the engineering tasks in the mining area, the driving routes and computational tasks of each UMV will not change quickly, which means that some network parameters will keep stable for a long period and we can use the devices including wireless signal detectors, navigation and positioning systems, etc. to measure them. Therefore, we can determine the output power consumption of UMVs in the whole mining area by numerical calculation. To minimize the UMVs’ power consumption, the objective function of the optimal link combinations and computational tasks assignments is formulated as follows:

|  |  |  |  |
| --- | --- | --- | --- |
| *M* |  *PL*)) |  |  |
| min(  (*P* *D* *P* *V* |  |  |
| *k* 1 |  |  |  |
| *s*.*t* . *U* {1, 2, | ,*M*},*U* *D* *U*,*UV* *U* *U* *D* | |  |
| *M*  *N* , *l ij* |  0 | (13) |  |
| *U D* {*i* | *Lii* |  1, *Lij*  0}, *i* *U* | |  |
| *U V* {*i* | *Lij* |  1, *Lii*  0}, *i*  *j* , *i*  *U* , *j* *U* | |  |
| *V k* {( *v* 1, *v* 2, , *v S* ) | *v* 1, *v* 2, | | , *v* *S*  {0,1}}, *k* *U* |  |



where *U* is the set of labels used to represent *M* UMVs; *U D* is the set of labels whose UMVs adopt the direct linkmode, and *U* *V* is the set of labels whose UMVs adopt the V2V relay mode. An *M*  *M* matrix **L** is used to represent all link states, and its elements *Lij* satisfy *Lij*  {0,1} . When *i*  *j* , *Lij* indicates the link between UMV *i* and the ECS; and when *i*  *j* , *Lij* indicates the link between

UMV *i* and UMV *j* . Meanwhile, An *M*  *S* matrix**V**is

used to represent the states of all computational tasks and its elements *vij* satisfy *vij*  {0,1} . When *vij*  1 indicates

that the task *j* in UMV *i* is sent to the ECS, otherwise indicates that the task *j* in UMV *i* is computed in on-board CPU.

Due to the limitation of the size of the mining area, the number of UMVs will not be too large. Furthermore, the driving route and area of UMV are relatively fixed, and owing to the existence of the SDN controller and the vehicular navigation system, the UMVs’ location and network status can be real-time monitored. In the light of the small number of samples and all of the possibilities can be estimated, a traversal method can be used to obtain the optimal solutions **L** and **V** , which can improve the accuracy of the output result in a short time.

To achieve this traversal method, an algorithm of optimal connection modes, uplink paths and computational tasks assignment shown in TABLE I is proposed. Because the number of UMVs and the number of computational tasks are finite, the set *U* *D* , *U* *V* and *V* *k* are also finite in the

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algorithm. Then, all possible link combinations **L**( **) and task assignments **V** (** ) can be enumerated, and finally we can obtain the optimal parameters by comparing their power consumption.

TABLE I

AN ALGORITHM OF OPTIMAL CONNECTION MODES, UPLINK PATHS AND COMPUTATIONAL TASKS ASSIGNMENT

**Algorithm: Optimal Connection Modes, Uplink Paths and Computational Tasks Assignment**

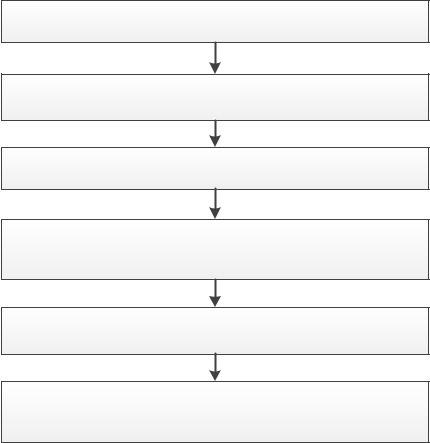
**Input: The locations of all UMVs** (*xi*,*yi*);

**Output: Link combinations and tasks assignment parameters L**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **and V ;** |  |  |  |  |  |  |
| 1 | Initialize *S* , *c* *k* , | *d k* , *qk* , *f l* , *f c* , |  | *h* |  | 2 / *N* , *B*1 and *B* 2 ; |  |
|  |  |  |
| **L**(**)**0**; ***N*; **V**(**) **0**; ** *N* ; | | | | | |  |
|  |  |
| 2 | Determine the number of UMVs in coverage area of each RSU | | | | | |  |
| signal: {*M* 1, *M* 2, | , *M* *n*} | | | | |  |
|  |  |
| 3 | Calculate the distances between every two UMVs and between | | | | | |  |
| UMV and RSU: *l* *ij* | and *l ii* | | | | |  |
|  |  |



assignments, and finally sends the design parameters to each UMV. Through this working process, SDN controller can manage the whole MEC network and the output power of UMV can be minimized.



Initialize the all parameters and status in mining area

Determine the distribution of RSUs and BSs

Collect the UMVs’location

Receive the resources and time requirements from

UMVs

Run the Algorithm to obtain the optimal results

Send the message of connection modes, uplink paths

and computational tasks assignment to each UMV

4

5

6

7

8

9

List all link path combinations, and *k* {1,

For *i*  *M* *k* : 1 :1

For *j*  *i* :1: *M k*

For **  1:1: ( *M* *k*  *i* 1)

For **  1 :1 : *M* *k* !

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Lij*(** )1, | *M k* ! |  | (**1)**  |  |
| ( *M* *k*  *i* 1)! | |  |
|  |  |  |

2, , *n*} ;



*M k* ! ** ;( *M* *k*  *i* 1)!

**FIGURE 5. Working process of an SDN controller in the mining area.**

**V. SIMULATION RESULTS**

In this section, we present the simulation results to demonstrate the performance of our proposed method and a simulation scenario is shown in Figure. 6. All UMVs are traveling at a low speed and randomly distributed in the

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 10 | End; End; End; End; | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| 11 | List all task assignment combinations, and *k* {1, 2, , *n*} ; | | | | | | | |  |
| 12 | For *i*  1 :1 : *M* *k* | | | |  |  |  |  |  |
| 13 | For | *j* 1:1: *S* | | |  |  |  |  |  |
| 14 | For ** 1:1: *j* | | | |  |  |  |  |  |
| 15 | For ** 1:1: 2*S* | | | |  |  |  |  |  |
|  |  |  | *S* | |  | 2 | *S* | |  |
| 16 | *v ij*(*i* )1, | | 2 | (** 1)1**  | |  | ** |  |
| *j* |  | *j* |  |
|  |  | 2 | |  | 2 | |  |  |  |
| 17 | End; End; End; End; | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | List all power consumption combinations with different link | | | | | | | |  |
| 18 | paths, | connection modes | | | and | |  | tasks assignments, and |  |
|  | *k* {1, 2, , *n*}; | | | |  |  |  |  |  |



1. For *i*  1 :1 : *M* *k*
2. For ** 1:1: 2*S*
3. For **  1 :1 : *M* *k* !

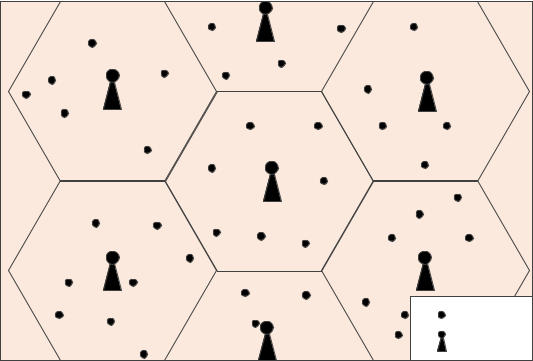
|  |  |
| --- | --- |
|  | *M* |
| 22 | Calculate the *Pi*  (*P D* *P V*  *P L*) |
|  | *k* 1 |

1. End; End; End;
2. Compare the *P*( *i* ) to obtain the **L** and **V** .

Figure 5 shows the working process of an SDN controller when UMVs send the offloading tasks to ECSs with the minimum power consumption. By regularly collecting the status and requirements of UMVs and RSUs in the entire mining area, SDN controller can determine the input parameters of the proposed traversal algorithm. Then it adopts the algorithm to generate the optimal combinations including the uplink paths, connection modes and task

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mining area. Additionally, all RSUs are evenly distributed in the mining area, so that the minimum RSUs can be used to make the wireless signal cover the entire mining area.



UMV

RSU

**FIGURE 6. Distribution of UMVs and RSUs in simulation scenarios.**

The main parameters of the simulation are presented in TABLE II, obtained from [9] and [30]. Then we can use the above algorithm to generate the optimal uplink paths, connection modes and computational tasks assignment under different simulation conditions. To illustrate the performance, we have compared the total transmission power of all UMVs for three different methods: the proposed method, the optimal tasks assignment method with the shortest path and the optimal tasks assignment method with the fixed path. Among them, the shortest path is a popular method that is widely used in UAVs networks and wireless sensors networks to reduce the end-to-end

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delay and transmission power, but it is likely to cause the accumulation of data on the common link and increase the transmission power consumption to ensure real-time performance.

TABLE II

SIMULATION PARAMETERS OF V2X COMMUNICATION WITH MEC SERVER

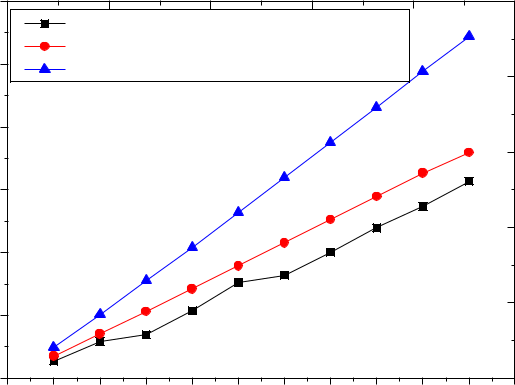
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | | | **Value** |  |
|  |  | Cooperative sensing, | 5-25000 Kbits/s; <3-100 |  |
|  |  | navigation and |  |
|  |  | ms; >1 Hz |  |
| Computational |  | positioning |  |
|  |  |  |
| Tasks |  | Emergency warning | 5-5000 Kbits/s; <3-100 ms |  |
|  |  | Traffic efficiency | 10-2000 Kbits/s; <1 s |  |
|  |  | Teleoperated driving | >10000 Kbits/s; 5-20 ms |  |
| Cellular network’ available bandwidth | | | 20 Mbps |  |
| IEEE 802.11p network’ available | | | 20 Mbps |  |
|  | bandwidth | |  |
|  |  |  |
| RSU coverage | | | 350 m |  |
| Simulations size of the mining area | | | Long: 2000-5000 m |  |
| Width: 1000-3000 m |  |
|  |  |  |  |
| Working frequency of UMV’s CPU | | | 2.7GHz, 4 cores |  |

In the mining area, the interval of the RUSs, the number of UMVs, the quality of wireless channel, the location of each UMV and the assignments of computational tasks are easy to change. Since the impact of the RSUs’ interval on power consumption is reflected in the number of UMVs, the quality of wireless channel, the location of each UMV and the assignments of computational tasks, we mainly analyze the total power consumption of the above three different methods under the influence of these four factors and the simulation results are depicted in Figure 7 to 10. The total power consumption in terms of the number of UMVs is presented in Figure 7, where the number of UMVs varies from 10 to 100. As the number of UMVs increases, the number of computing tasks will also increase, which can raise the computational power consumption of the UMV’s computer and the communicational power consumption of sending offloading tasks. Advantageously, the increase of UMVs will make the linking paths and connection modes more flexible, thus compared with the optimal tasks assignment method with the shortest path and the optimal tasks assignment method with fixed path, the power consumption of the proposed method is lower. Figure 8 assesses the total power consumption in terms of the ratio of gain to noise in the wireless channel. The ratio of gain to noise can directly have effect on the SNR, and the higher SNR means the less communicational power consumption when uploading task packets. Figure 9 evaluates the total power consumption in terms of the average interval of UMVs. In this paper, the average interval of UMVs is changed by adjusting the simulation size of the mining area when the number of UMVs is constant. The average interval of UMVs increases, the transmission distances between every two UMVs also increase, which can cause more path loss when adopting V2V links to sending offloading tasks. When the average interval changes from 10 to 100 meters, the total power consumptions of the three methods all have raised slightly.

Figure 10 shows the total transmission power in terms of the total capacity of each UMV’s computational tasks. When the number of tasks is constant, the capacity of each task determines the load of the network link. To ensure the real-time performance of the task, it is necessary to increase the power to increase the transmission rate of the link.

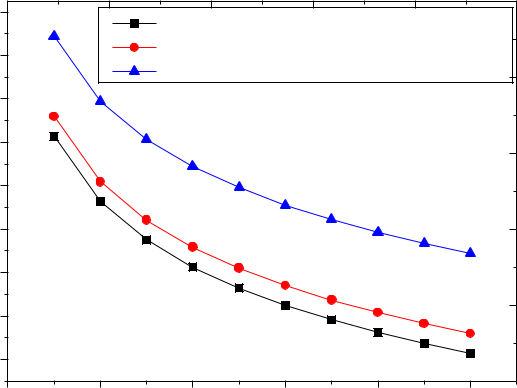
In summary, based on the above evaluations, the proposed method based on joint connection modes, uplink paths and computational tasks assignment can reduce the power consumption by approximately 20% compared with optimal tasks assignment method with the shortest path and 40% compared with optimal tasks assignment method with the fixed path, which demonstrates the effectiveness of the proposed method.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 12 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | Proposed method | | |  |  |  |  |  |  |  |  |
|  | 10 |  | Optimal tasks assignment with shortest path | | | | | | |  |  |  |  |
| **(dB)** |  | Optimal tasks assignment with fixed path | | | | | | |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Consumption** | 8 |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Power** | 4 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Total** | 2 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 0 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |  |



**Number of UMVs in Mining Area**

**FIGURE 7. The total transmission power of three different methods in terms of the number of UMVs. (|*h*|2/*N*=0.5)**



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 22 |  | Proposed method | |  |  |  |
|  |  |  |  |  |  |
| **(dB)** | 20 |  | Optimal tasks assignment with shortest path | | | |  |
|  | Optimal tasks assignment with fixed path | | | |  |
|  |  |  |
| 18 |  |  |  |  |  |  |
| **Consumption** |  |  |  |  |  |  |
| 16 |  |  |  |  |  |  |
| 14 |  |  |  |  |  |  |
| 12 |  |  |  |  |  |  |
| **Power** |  |  |  |  |  |  |
| 10 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Total** | 8 |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |  |

**Ratio of Gain to Noise： |*h*|2/*N***

**FIGURE 8. The total transmission power of three different methods in terms of the ratio of gain to noise: |*h*|2/*N*. (*M*=100)**

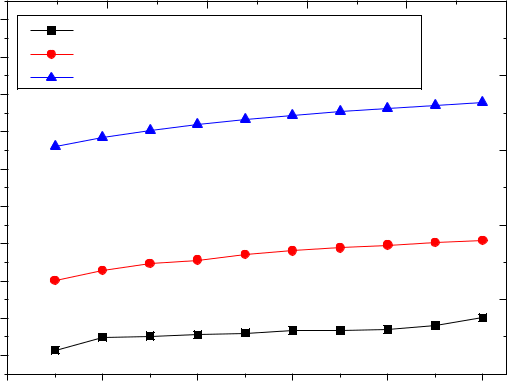
|  |  |
| --- | --- |
| VOLUME XX, 2020 | 9 |

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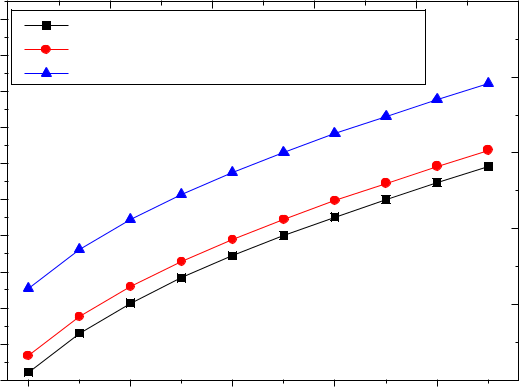


|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 14 | Proposed method | |  |  |  |  |
|  |  |  |  |  |  |
| **(dB)** | 13 | Optimal tasks assignment with shortest path | | | |  |  |
| 12 | Optimal tasks assignment with fixed path | | | |  |  |
|  |  |  |  |  |  |
| **Consumption** | 11 |  |  |  |  |  |  |
| 10 |  |  |  |  |  |  |
| 9 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Power** | 8 |  |  |  |  |  |  |
| 7 |  |  |  |  |  |  |
| **Total** | 6 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | 5 |  |  |  |  |  |  |
|  | 0 | 20 | 40 | 60 | 80 | 100 |  |



**Average Interval of UMVs (m)**

**FIGURE 9. The total transmission power of three different methods in terms of the average interval of UMVs. (*M*=100; |*h*|2/*N* =0.5)**



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 22 | Proposed method |  |  |  |  |
|  |  |  |  |  |  |
| **(dB)** | 20 | Optimal tasks assignment with shortest path | | |  |  |
| 18 | Optimal tasks assignment with fixed path | | |  |  |
|  |  |  |  |  |
|  |  |  |  |  |  |
| **Consumption** | 16 |  |  |  |  |  |
| 14 |  |  |  |  |  |
| 12 |  |  |  |  |  |
| 10 |  |  |  |  |  |
| **Power** |  |  |  |  |  |
| 8 |  |  |  |  |  |
|  |  |  |  |  |  |
| **Total** | 6 |  |  |  |  |  |
| 4 |  |  |  |  |  |
|  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |
|  | 10 | 20 | 30 | 40 | 50 |  |

**Total capacity of each UMV's Tasks (Mbits/s)**

**FIGURE 10. The total transmission power of three different methods in terms of the total capacity of each UMV’s tasks. (*M*=100; |*h*|2/*N* =0.5)**

**VI. CONCLUSION**

In this paper, we analyzed the UMVs’ computational power consumption and communicational power consumption and then compared the total transmission power for UMVs connecting to an ECS by adopting the direct connection mode and the V2V relay mode in the mining area. Based on the analyzed results, we concluded that the joint uplink paths, connection modes and computational tasks assignment method can effectively reduce power consumption. Moreover, a traversal algorithm is proposed to determine the optimal parameters about the uplink paths, connection modes and computational tasks assignment combinations under power consumption constraints. Correspondingly, a simulation experiment was designed to prove the effectiveness of the algorithm and the results demonstrated that our method can effectively reduce the power consumption by approximately 20% compared with optimal tasks assignment method with the shortest path and 40% compared with optimal tasks assignment method with the fixed path. Therefore, by adopting the proposed method, UMVs can achieve the purpose of saving UMVs’ energy and furthermore, it can improve their production efficiency

and working time.

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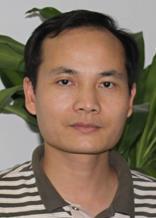
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