Clustering WSN for Coal Mine Using Software Defined Network

Shi Yanfeng, Hu Shengbo, Shu Heng, Mo Jinrong, and Yan Tingting

***Abstract*—The clustering WSN is very important to coal mine safety. The recent development of information and communication technologies makes it practical to realize a new WSN using SDN (Software Defined Network). So, this paper is concerned with designing the clustering WSN for coal mine using SDN. First, the SDN architecture is described. Then the clustering WSN of laneway for coal mine is presented. By introducing the concept of domain, the architecture of clustering WSN using SDN is proposed via adding gateway nodes. It is emphasized that the controller not only manages the traffic and routing in the domain, but also manages the security of the domain. Finally, a communication reliability mechanism of intra-cluster and inter-cluster is presented. Hence, it is helpful to design and optimize the clustering WSN for coal mine using SDN.**

***Index Terms*—Cola mine, clustering WSN, SDN, data plane, control plane.**

I. Introduction

After more than 50 years of development, the Internet has become the social foundation and important information infrastructure, and has a deep influence on the fields of economy, culture, military affairs and so on, far beyond the original pure military, education and scientific research purpose. However, because of using the architecture of TCP/IP, the best effort and no QoS guarantee data delivery, facing the heterogeneous and large scale access today, the Internet do not satisfy more and more rapid expansion of the global network.

The rapid expansion of the global network has a direct impact on changes in international industries. In fact, whether the US "Advanced Manufacturing Partnership", the Germany "Industry 4.0", or “Made in China 2025" all are taking manufacturing as the core, implementing information space and physical space high integration with information network technology including IOT (Internet of Things). Therefore, accelerating the development of information technology and constructing the future network has become a global consensus, and software defined network (SDN) is a research hotspot in [1]-[4] future network technology, getting more and more attentions.

Naturally, how to integrate wireless sensor networks (Wireless Sensor Network, WSN) into the SDN is an easy question to think about. Further, how to take into account the cluster (hierarchical) [5]-[7] network topology for coal mine safety monitoring. Finally, how to design the clustering WSN for coal mine using SDN?

Over the past ten years, wireless sensor networks have been studied and applied in coal mine. W.Yang presents a coal mine wireless and integrated security monitoring system which combine wireless sensor network and wire monitoring network [8]. C. Zhao describes a strategy for the classification of coal mine status based on sensed data by WSN and the use of unsupervised neural network-the Self-Organizing Map [9]. And S.Vandana *et al* design a monitoring system based on Zigbee technology to build wireless sensor network [10].

Also it can be seen that integrating WSN into SDN is studied in recent years. Luo *et al* propose the software defined wireless sensor network (Software Defined Wireless Sensor Network, SD-WSN) concept, and have carried on the research of management WSN using SDN in 2012 [5]. Zeng and others have studied the evolution of the software defined sensor networks, and integrate sensor nodes into cloud computing with help of SaaS, called sensing as a service [11]. Gante *et al* propose a WSN base station architecture based on SDN, and use the controller in the SDN as the base station, but did not analyze how the sensor nodes communicate with each other [12]. However, the above work does not consider the network topology, especially the cluster (hierarchical) network topology. Therefore, this paper proposes a software defined cluster (hierarchical) sensing network architecture, in order to provide some reference for the design and optimization of clustering WSN for coal mine using SDN.

The rest of the paper is organized as follows. Section II presents the software defined network architecture. Section III describes the clustering WSN using SDN. Finally, the paper concludes in Section IV.

II. Software Defined Network Architecture

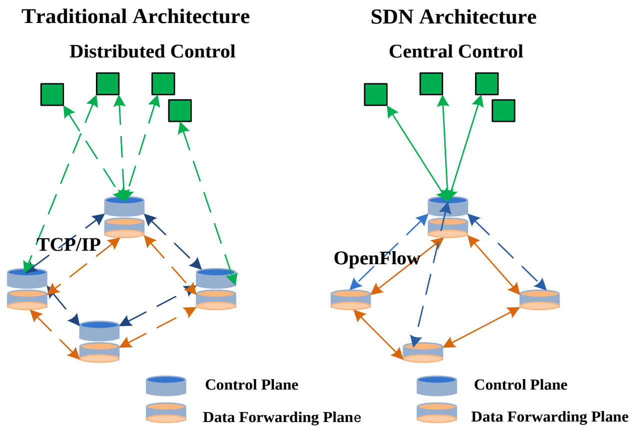

Fig. 1. The software defined network architecture.

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With the advent of the OpenFlow protocol , especially the OpenFlow experimental network demonstrated by Pro.McKeown at the SIGCOMM Conference in 2008, the SDN architecture gradually becomes clear [13]. In 2011, Deutsche Telekom, Google, Microsoft, Facebook, Verizon and other companies jointly established ONF (Open Networking Foundation) organization [14], in order to promote the OpenFlow protocol as the representative of the SDN technology through the industry alliance. Fig. 1 is the SDN architecture based on OpemFlow protocol.

In Fig. 1, each data forwarding plane is equivalent to a site and runs the OpenFlow controller and network control applications (Network Control Application, NCA). The global control plane is composed of logically centralized applications (such as SDN gateways, global traffic engineering servers, etc.) and centrally controls the entire network through the NCA of each site.

The OpenFlow controller is deployed with a Traffic Engineering Agent (TEA) program. The link state information of each OpenFlow switch is sent to the SDN gateway via TEA, and the SDN gateway is aggregated and sent to the traffic engineering server. The traffic engineering server maps each flow to the IP-IP tunnel, and sends the allocated bandwidth to the OpenFlow controller through the SDN gateway. Then the OpenFlow controller mounts the bandwidth to the forwarding table of OpenFlow switch. So, it is realized to the path planning of network traffic.

In addition, according to the data provided by Google , the traffic engineering completely relies on SDN/OpenFlow, the utilization of network resources is greatly improved, and the average bandwidth utilization rate can reach 95% using SDN technology.

Thus, SDN separates the control plane from the network switches and the data plane of routers data separation. The SDN controller implements the functions of collecting the network topology, calculating the routing, generating the flow table generation, managing and controlling the network. The network equipment is only responsible for forwarding traffic and strategy execution. The separation of the data forwarding from control makes the control logic centrally. And this also makes the SDN controller has the static topology, the dynamic forwarding table, the utilization of resources and the fault status of the global network. So, this opens the network capacity.

III. The Clustering WSN Using SDN for Coal Mine

A. The Clustering WSN of Laneway for Coal Mine

Considering the narrow and bad environment of the laneway for coal mine roadway, it is suitable to use hierarchical cluster wireless sensor network for improving the coverage and connectivity of sensor networks. The cluster wireless sensor network consists of sensor nodes, relay nodes and sink nodes. The sensor nodes collect data automatically. The multiple sensor nodes form a cluster and the relay node is the cluster head. The relay node transfers the collected data by the sensor node in the cluster to the sink node. The relay nodes can communicate with each other, so as to form a multi hop routing, or can be directly connected to the sink node. Fig. 2 is a cluster wireless sensor network topology, and Fig. 3 is a two-dimensional model of the clustering sensor network of the laneway for coal mine.

B. The Clustering WSN of Laneway Using SDN

As shown in Fig. 2 and Fig. 3, each cluster consists of one relay node and several sensor nodes. And the proposed clustering WSN of laneway for mine coal using SDN needs to add a gateway node, as shown in Fig. 4. Each cluster forms the domain of SDN, and the domain consists of cluster head, gateway and sensor nodes. Each relay node is the cluster head (Cluster Head, CH) in the domain, and the cluster head is the controller, which manages the sensor nodes in the domain and organizes the routing. The status of cluster heads is equal. The cluster heads can be completely peer to peer access and communication, and the routing rules are also the same. Based on the above methods, the parameters can be configured, and the data can be collected or stored in the domain. And the data can be transferred to the sink node or other domains. The gateway is the bridge node between the cluster head and sensor nodes.

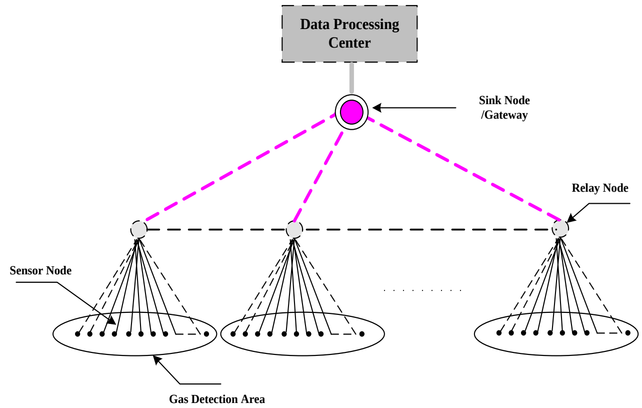

Fig. 2. The clustering WSN topology for coal mine.

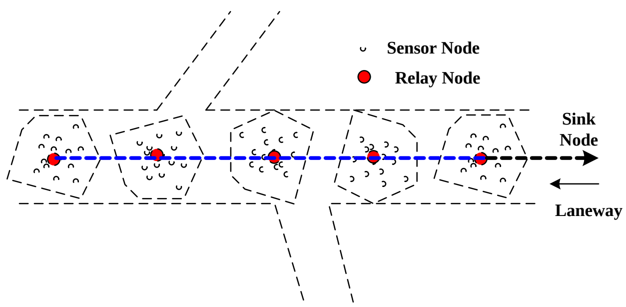

Fig. 3. The 2D model of the clustering WSN for coal mine.

Once the cluster head fails, the sensor nodes in the domain are temporarily unable to access, and the routing must be reorganized. The gateway node is responsible for inter domain communication. Once the gateway node fails, the inter domain communication will be interrupted, and the relevant domain will become an information island.

In the base station architecture proposed by Gante [10], the SDN controller is combined with the WSN, and the controller needs to know the topology of the entire network. Therefore, this method can reduce energy consumption and make the best route decision. Using this architecture, SDN cluster heads can not only manage the entire domain well, but also monitor the attacks inside and outside the network effectively. This is also what the next generation network needs to pay attention to. Moreover, SDN cluster heads play the role of security guard in the domain boundary because of this architecture. For example, if the service is fire detection, the sensor nodes can detect the smoke and temperature in laneway, then transmit these data to SDN cluster head.

C. Clusters Interconnection

With the help of the boundary controller, all domains using SDN can be interconnected in Fig. 4. In this way, the concept of software defined sensor networks will be extended. Each domain has its own SDN controller that controls all traffic within the domain. In each domain, SDN cluster heads have their own security policies and management policies, and each boundary controller assigns security rules and routing criteria. Using this architecture, network security can be guaranteed. That is, when a sensor node needs to transfer data to another domain, the data stream must be forwarded to the domain security controller.

When a SDN cluster head fails, another controller is required to avoid system failure. It is help to improve system reliability and fault tolerance. In the OpenFlow specifications, two modes of operation are proposed for SDN by multiple controllers: equal and master-slave interaction. For equal interaction, all SDN cluster heads are peer - to peer, and have a global view of the entire network. And the controller can exchange data in all domains. In master slave interaction, the master controller can interconnect with multiple slave controllers and acquire data from the controllers. In this environment, each SDN cluster head sends data to the main controller.

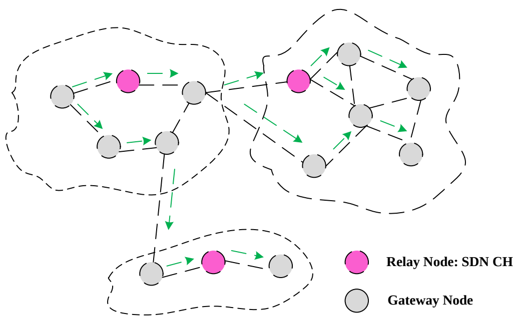

Fig. 4. The Clusters interconnection.

D. Communication Reliability Mechanism of Intra-Cluster and Inter-Cluster

As shown in Fig. 2, each cluster is linked together by each cluster's gateway, and the gateways and relay nodes are controlled by the SDN controller. Once the wireless link becomes bad so that the gateways cannot connect to the controller, the controller will become unavailable, and the networks will interrupt. So, this paper proposes communication reliability mechanisms to ensure normal communication when the SDN controller is unavailable, including a connection-state processing mechanism, a new link layer mechanism, and a network layer mechanism into the data plane to keep the intra-cluster's and the inter-cluster's communication normal [15].

The connection-state detection mechanism: The connection state is the link state between the controller and each gateway; This connection-state detection mechanism can detect the real-time state by probing messages, such as the OpenFlow Echo message. Failure recovery time depends on the detection time of controller failure; therefore, to get the latest connection state between the SND controller and relay nodes as soon as possible, it dynamically adjusts the probe's sending interval based on echo message's Round-Trip-Time.

The stateful match mechanism: The connection states mainly consist of two states: connection-state and disconnection-state. Connection-state means that the cluster controller informs the packet how to forward in relay nodes and gateways. In contrast, disconnection-state means that the cluster controller is unavailable and relay nodes will enter failure recovery mode in sensor networks. To apply this connection state into both the controller and the relay modes, a match field named connection-state is extended in OpenFlow protocol.

The link layer mechanism: When relay nodes enter disaster recovery mode, it needs a link layer mechanism to keep the network normal. This link layer mechanism is extended as a new OpenFlow protocol action, so the controller can use OpenFlow API to install an entry that consists of a flexibly action. The proposed mechanism is similar to the traditional switch L2-mechanism but can be invoked and inserted in the flow-table by a controller application, which maintains the flexibility of SDN. After a packet matches this entry consisting of an action successfully, then it will implement this action. This action process entails that the relay node can parse the ingress port and mac address of the packet's header. Then, a new entry will be generated and updated by this parsing information, which can forward a similar packet from the opposite direction; therefore, this new link layer mechanism can ensure basic L2 communication in an intra-cluster network when the controller becomes unavailable .

The network layer mechanism: When the network enters disaster recovery mode, inter-cluster communication still needs to rely on gateways. However, after the gateways lose control of the controller, gateways do not know how to route the packets to another cluster, seriously restricting the inter-cluster communication. So the network layer mechanism in the data plane for two types of packets in case of controller failure. The first type of packet is that which will transfer from this cluster to another cluster. This is designed to insert a stateful entry into gateways, which can forward this type of packet to a neighboring cluster when the loss of controller happens. Then, the controller of the neighboring cluster can correctly direct the packet. The second type of packet is that which will enter this cluster. For these packets, the gateway switch will implement an ARP mechanism to obtain the next hop mac address so that it can finish packet routing in case of controller failure.

IV. CONCLUSION

With the advancement and convergence of existing information technologies such as cloud computing, IOT and SDR (Software Defined Radio, SDR), we believe that WSNs are not only necessary, but also inevitable in the next-generation sensor network. Nowadays, there is widespread concern about a sensor node and a SDN controller, and few people have studied the deployment of clustering WSN using SDN and SDN controllers. By introducing the domain concept, we propose the clustering WSN architecture of Laneway for coal mine using SDN, and emphasize that the controller not only manages the traffic and routing in the domain, but also manages the security of the domain. So, the proposed architecture can not only realize the distributed security management of network, but also manage the traffic in a cooperative way. Finally, a communication reliability mechanism of intra-cluster and inter-cluster is presented. Next, we will build a test-bed in order to experiment the proposed architecture.

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