On the Expansion of Access Bandwidth of Manufacturing Cloud Core Network

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***Abstract*—This paper discusses the construction and a logical aggregation method of multi-access link manufacturing cloud core networks. The key technologies involved in the logical aggregation of multi-access link manufacturing cloud core networks are discussed in detail. Focusing on the key technologies including access load scheduling, access link flow monitoring, link aggregation control, and gateway integration, the principle and an corresponding effective approach have been developed to effectively expand the access bandwidth of a manufacturing cloud core network through multi-access link aggregation. A preliminary link aggregation implementation model has been developed according to the proposed aggregation structure and the proposed key technologies, which provides supports to the maximization of the performance of manufacturing cloud core network.**

***Index Terms*—Manufacturing Cloud, Logical Bandwidth, Traffic Monitoring, Load Scheduling, Link Aggregation**

I. INTRODUCTION

With the continuous transformation of the manufacturing industry, high-end manufacturing not only has been facing unprecedented challenges, but also encountering excellent opportunities for innovation and development. Literature[1]-[3] provided a new idea for the sharing of manufacturing resources and capacities, which is known as manufacturing cloud. The key technologies related to manufacturing cloud are comprehensively discussed in the literature as well. The spread and the application of manufacturing cloud provide faster channels for the technology collaboration and achievement transformation between many research institutes and manufacturing enterprises.

Manufacturing Cloud integrates a number of technologies[4]-[11] including the manufacturing information, cloud computing, and internet of things. It centralizes the allocation of manufacturing resources, research and innovation resources, and management resources, and has a wide extension on its services through information network. This provides an efficient, convenient, service-on-demand, and reliable collaborative services to manufacturing enterprises.

The key to the smart expansion of manufacturing cloud core network access bandwidth is to effectively superimpose the bandwidth of each access link in order to form a single logical link and make each physical access link collaborate with each other smartly according a certain load balancing strategy. This will greatly increase the total carrying capacity of the logical link. Manufacturing Cloud core network is connected to WAN through access links. Terminal manufacturing systems that locate at different regions are connected to the manufacturing cloud core network through WAN. Therefore, the total link bandwidth of the access to WAN for the manufacturing cloud core network is one of the key factors that affect the performance of the manufacturing cloud system. In this paper, based on literature[12]-[20] and technologies including load scheduling, flow monitoring, smart link aggregation control, and gateway integration, we propose an approach that smartly expands the total access bandwidth of the manufacturing cloud core network and balances the total load flow according to the sub-bandwidth of each physical link. We also give an in-depth discussion regarding the key technologies involved in this approach. The proposed method breaks through the restriction in traditional link aggregation approaches that each participating link must have the same transmission rate.

II. MANUFACTURING CLOUD CORE NETWORK ACCESS STRUCTURE AND ACCESS LINK AGGREGATION PRINCIPLE

The data transmission between the manufacturing cloud core system and terminal manufacturing system has to go through access links. The total bandwidth of access links determines the response performance of a large number of concurrent accesses from the terminal manufacturing systems to the manufacturing cloud core network. Manufacturing cloud core network is connected to WAN through multiple access links with same or different bandwidths and rates. All the access links share the massive data transmission tasks produced by the concurrent accesses from terminal manufacturing systems through load scheduling. The structure design of the access links and the link aggregation method determine

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the expansion capacity and costs of the access link bandwidth.

A. Manufacturing Cloud Core Network Access Link Structure

The manufacturing cloud core network is connected to WAN and terminal manufacturing systems through multiple physical access links, as shown in Fig.1.

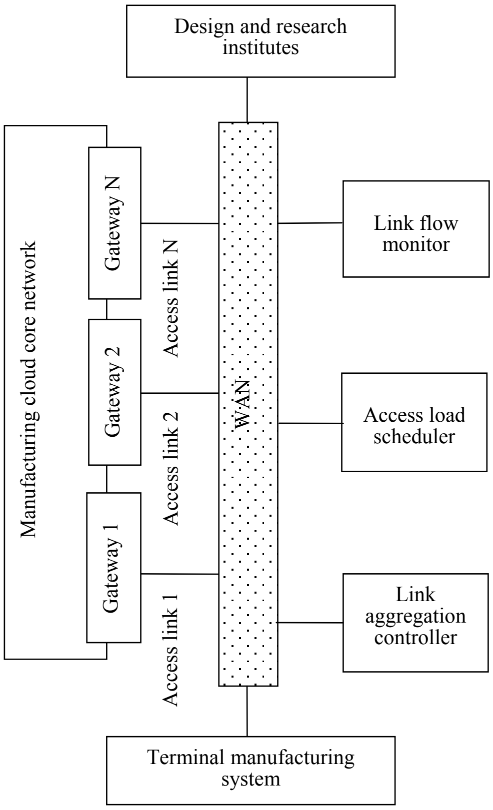

Figure.1 The link structure of a manufacturing cloud system

It can be seen from Fig.1 that all the N physical access links connecting the manufacturing cloud core network and WAN are able to transmit data from terminal manufacturing systems, which reduces the load pressure on a single access link to a certain extent.

Under the circumstances with no load scheduling strategy, the concurrent accesses to the manufacturing cloud core network from multiple terminal manufacturing systems could be transmitted on a single or a few access links and other access links receive very little data flow or are even in idle state. When the bandwidth of a single or a few access links is not large enough to meet the requirements of large real-time data transmission, overload will happen and terminal manufacturing systems will not obtain the required production data in time, which could seriously affect the production of online manufacturing enterprises. In order to prevent the situation where some access links are overloaded and at the same time others are in idle state and effectively use the physical bandwidth of each access link, the accesses from terminal manufacturing systems should be allocated according to the instantaneous carrying capacity of each access link. The allocation helps the realization of the flow balancing among multiple physical access links and the logical aggregation of all the physical access links, which achieves the goal of effective expansion of the total access bandwidth. In this paper, a composite structure consisting of a load scheduler, a link flow monitor, a link aggregation controller, and an integrated gateway is used to resolve the logical aggregation problem among multiple physical access links.

B. Manufacturing Cloud Core Network Access Links Aggregation Principle

In order to realize the flow balancing of each physical access link and the effective logical aggregation among access links, the access load form the terminal manufacturing systems are allocated to different physical access links through a pre-positive access load scheduler according to the instantaneous carrying capacity of each physical access link. The scheduling is performed in order. The total access load for each physical access link is proportional to its bandwidth. The access load allocated to each physical link is then determined together by the access load scheduler and the amount of IP addresses bound to the gateway of the link. As a result, an effective superimposition of each physical access link can be realized by the load scheduling strategy. Also, multiple physical access links are aggregated to one logical link with wider bandwidth, completely expanding the total carrying capacity of the access links. The response time could be reduces as well. For those physical access links whose actual load is close to the limits, the load scheduler will temporarily stop allocating loads to them. The load allocation will resume once the load decreases below some safety value. When the actual loads of all the access links reach the limit values, the system alerts the network administrator. The detailed link aggregation is shown in Fig.2.

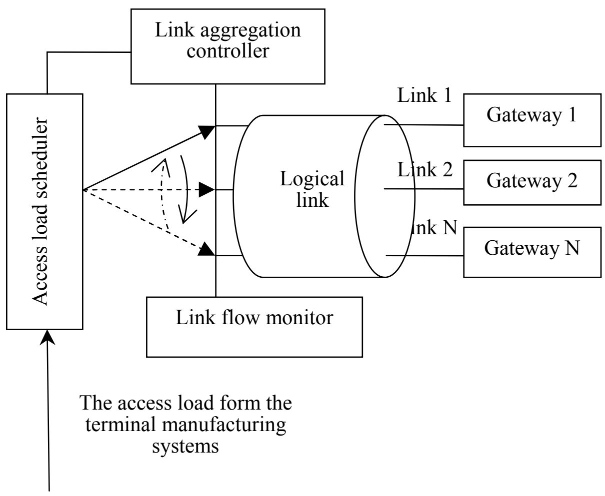

Figure.2 Multiple physical access link aggregation principle

In Fig.2, the link flow monitor monitors the load flow of each access link in real time. Link aggregation controller adjusts the amount of IP addresses bound to each access gateway external network card according to the load flow of each physical access link. At the same time, the controller also adjusts the amount of IP addresses mapped by the same application domain set in the load scheduler in WAN.

III. Key Technologies for Manufacturing Cloud Core Network Multi-access Link Aggregation

A. Access Load Scheduler

Access load scheduler is used to allocate the total load from the terminal manufacturing systems to different access links according to the instantaneous carrying capacity of each physical access link. This function is realized by the mapping between a same application domain and multiple IP addresses. Several IP addresses are grouped based on the access links they belong to. Each group corresponds to one access gateway. All the groups are sort in order and form an IP address list. The domain name point accesses the IP address list in order.

In the IP address list, the number of IP addresses in each group is different. The total load produced by application domain name accessing the manufacturing cloud core network is allocated to different physical access links successively according to the order of each group and the number of IP addresses in the group. The number of groups is determined by the number of physical access links. The number of IP addresses in each group is adjusted by the link aggregation controller according to the link loads. The principle of the access load scheduler is shown in Fig.3.

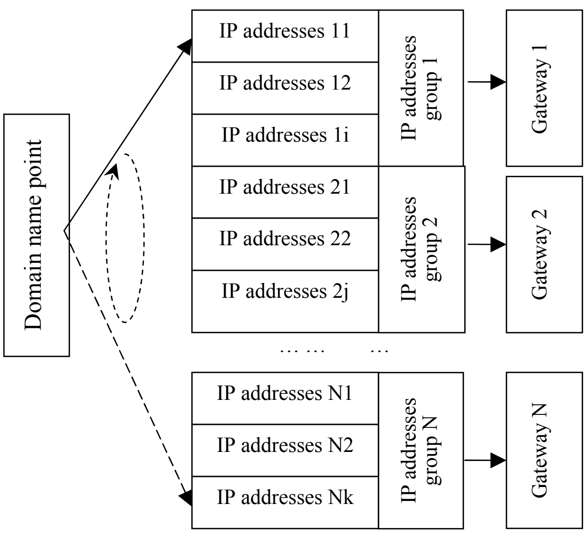

Figure.3 The principle of the access load scheduler

where i, j, and k represent the number of IP addresses in IP address group 1, 2, and N, respectively.

B. Link Flow Monitor

The link flow monitor scans the data flow of each access gateway netcard in real time. It also provides statistical analysis about the data flow for certain time periods. The analysis results for the flow of each single physical access link f(x) and the results for the total flow of all the access links G(x) are obtained. G(x) is calculated according to the following equation.

$$G(x)=F(x)_1+F(x)_2+\ldots+F(x)_N, \quad (1)$$

where 1, 2, …, N are the indices of each access links.

First, G(x) is compared with the total carrying capacity of all the access links MAX to determine the current working status of the manufacturing cloud core network access links. If $G(x) \geq MAX$, the system overloads and alerts will be sent. If $G(x) < MAX$, the f(x) of each access link will be sorted by their magnitude and the index of corresponding access link will be recorded. Then, the flow statistical results of each access link will be compared with the upper and lower threshold M1 and M2 in order to adjust the load allocation strategy, where M1 and M2 are determined by the percentage of the maximum carrying capacity of a single physical access link depending on the circumstances. The statistical analysis for the loads and the output results are shown in Table I.

In table I, C1 represents the condition 1, C2 represents the condition 2, C3 represents the condition 3, $f(x)_{1,2,\ldots,N}$ represent the load flow of the 1st, 2nd, …, Nth access link.

TABLE I.
STATISTICAL ANALYSIS AND OUTPUT RESULTS FOR THE LOAD

C1	C2	C3	Access link status	Output Result
$G(x) \geq MAX$			Overload	System alert
$G(x) < MAX$	$f(x) \geq M1$	All $f(x)_{1,2,\ldots,N}$ greater or equal to M1	Heavy load for all links	No aggregation strategy implemented. System administrator to be notified.
		Not all $f(x)_{1,2,\ldots,N}$ are greater or equal to M1	Heavy load for single link	Notify the link aggregation controller to reduce the upcoming accesses to this link
$G(x) < MAX$	$f(x) \leq M2$	All $f(x)_{1,2,\ldots,N}$ are less or equal to M2	Idle state for all links	No aggregation strategy implemented
		Not all $f(x)_{1,2,\ldots,N}$ are less or equal to M2	Idle state for single link	Notify the link aggregation controller to increase the upcoming accesses to this link

C. Link Aggregation Controller

Link aggregation controller controls the access load scheduler and the access gateway according to the output results of the link flow monitor. All the available external IP addresses by the manufacturing cloud core network are stored in the controller. When $G(x) < MAX$, the aggregation control strategy is based on the simultaneous increase or decrease of the number of IP addresses of the access load scheduler and the number of IP addresses bound in the access link gateways. The detailed process is shown in Fig.4.

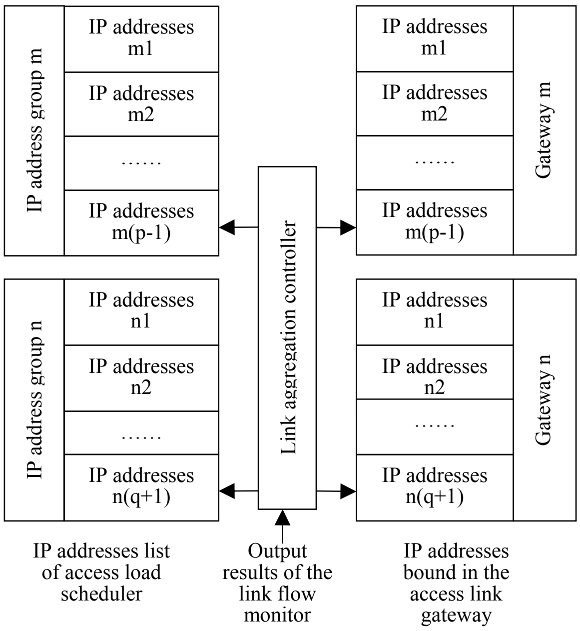

Figure.4 Control strategy for the link aggregation controller

In Fig.4, p and q are the number of IP addresses in the IP address group m and n as well as the IP addresses bound to gateway m and n, respectively.

When the mth (1≤m≤N) link overloaded, i.e. $f(x)_m \geq M1$, if not all the f(x) of the access links are greater or equal to M1, the link aggregation controller will automatically change the application domain name and the IP address mapping list in the access load scheduler to reduce the number of IP addresses in the mth IP address group. The number of IP addresses bound to the mth access link gateway will be reduced as well. Meanwhile, the number of IP addresses in the nth IP address group corresponding to the nth (1≤n≤N) link will be increased in the access load scheduler. The amount of IP addresses bound to the nth access link gateway will be increased as well.

When some access link is in idle state, for example, for the nth link, f(x)n≤M2, if not all the f(x) of the access links are less or equal to M2, the link aggregation controller will also change the application domain name and the IP address mapping list in the access load scheduler to increase the amount of IP addresses in the nth IP address group and simultaneously increase the amount of IP addressed bound to the nth access link gateway. At the same time, the amount of IP addresses in the IP address group m (1≤m≤N) corresponding to the link with the largest load is reduced in the access load scheduler. The amount of IP addresses bound to the mth access link gateway is reduced as well.

The link aggregation controller decreases the load for the mth heavy-loaded link and increases the load for the nth link which has a little load by the above method. Finally, the logical superimposition of the bandwidth of each physical access link is completed and the aggregation of access links is realized.

D. Access Gateway

Access gateway is a connection device between each physical access link and the manufacturing cloud core network. Multiple IP addresses are bound to the external network card of each access gateway. These IP addresses match the corresponding IP address group in the IP address list in the access load scheduler and guide the visits from terminal manufacturing systems to the manufacturing cloud core network into different access links. Then, the load scheduling and the logical aggregation of different physical access links can be realized. The matching relation between the binding IP addresses of each access link gateway and the IP address groups in the access load scheduler is shown in Table II.

TABLE II.
MATCHING RELATION BETWEEN THE GATEWAY BINDING IP ADDRESSES AND THE IP ADDRESS GROUPS IN THE ACCESS LOAD SCHEDULER

Gateway name	Gateway 1	Gateway 2	···	Gateway N
IP address group bound to gateway	IP address group 1	IP address group 2	...	IP address group N
IP address group in the access load scheduler	IP address group 1	IP address group 2	...	IP address group N

IV. TESTING, RESULTS, AND DISCUSSIONS

A. Testing Environment

For the convenience of the testing and evaluation of the smart expansion technologies of the manufacturing cloud core network access bandwidth, we used two access links and ten testing terminals that continuously accessing the manufacturing cloud core network. The detailed parameters are shown in Table III.

TABLE III.
PARAMETERS FOR THE TESTING ENVIRONMENT

Access links	Number of manufacturing cloud core networks	Number of testing clients
Access link 1，100Mb Access link 2，100Mb	Three server (1 cluster)	12

Due to the uncertainty during the operation of network, in order to verify the generality and reliability of the key technologies of the smart expansion of manufacturing cloud core network access bandwidth, different network segments of the same location of all the tested terminals were selected in the testing. The sampling time of link flow was one minute. Link flow data of 10 time points with and without link aggregation were collected respectively.

B. Results and Discussions

Data flow as a function of time of access link 1 and 2 without link aggregation being implemented is shown in Fig.5. Data flow as a function of time with link aggregation implemented is shown in Fig.6.

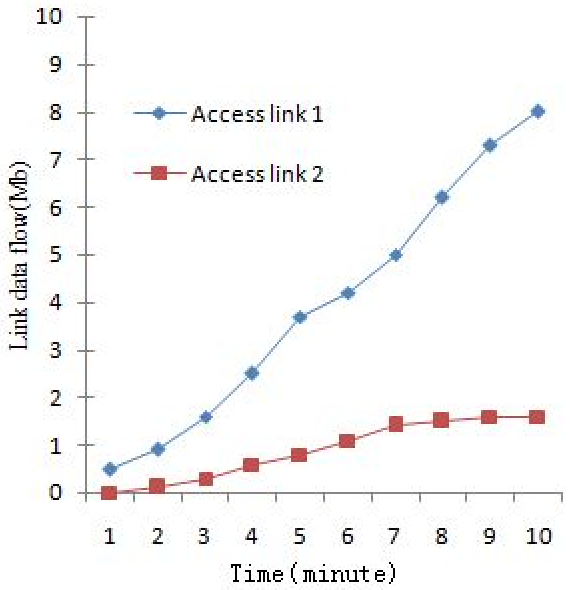

Figure.5 Link flow as a function of time without link aggregation

It can be seen from Fig.5 that when there is no link aggregation, with the increase of time and concurrent accesses, the total data flow increases. At the same time, the increase of the data flow in access link 1 and 2 is uncontrollable in a way that the data flow is relatively centralized in access link 1 and the bandwidth of access link 2 are not sufficiently used. The distribution of load is not uniform. When the total flow of the system is large, access link 1 will be blocked or even fail.

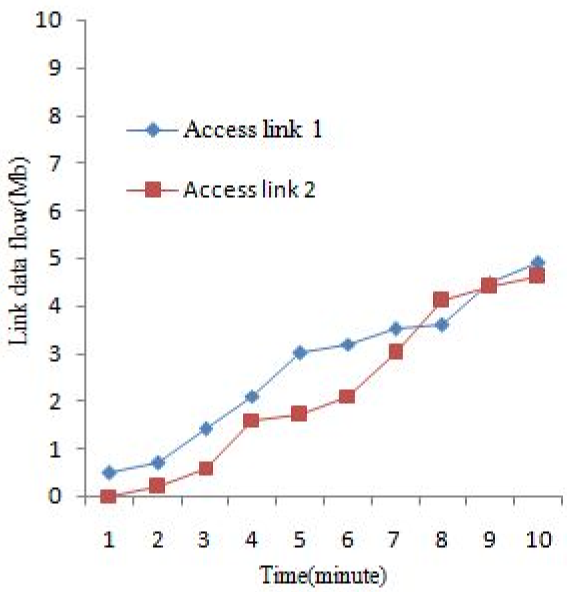

Figure.6 Link flow as a function of time with link aggregation

From Fig.6, it can be seen that after implementing link aggregation, under the same testing environment, with the increase of time and the data flow caused by concurrent accesses, the data flow in access link 1 and 2 grows slowly in a same pace. Additionally, the data flow in access link 1 and 2 are gradually approaching to each other. After the seventh testing time point, there is a jump in the data flow of access link 2 and the data flow of access link 2 exceeded that of access link 1. With the increase of total access flow, at the ninth testing time point, there was also a jump happened in the data flow of access link 1, which made the data flow exceeded that of access link 2. The results show that under the control of the link aggregation strategy, both physical access links are able to share the data flow generated by the accesses of the terminal manufacturing system. The bandwidth of each access link was sufficiently used and the logical aggregation was realized.

It can also be seen from the trends the data flow of access link 1 and 2 that of it took about seven minutes for the link bandwidth expansion technology and strategy to reach an ideal working condition., The link aggregation became stable right after the alternative jumps of the data flow of each access link happened. Similarly, when the total access data flow gradually decreases, the link aggregation will result in alternatively downward jumps for the data flow of each access link.

Through the above analysis, it is illustrated that the smart access bandwidth expansion technology for manufacturing cloud core network solves the smart aggregation problem for multiple physical access links and realizes the balancing of access flow among all the physical access links.

V. CONCLUSIONS

Currently, many core networks possess multiple physical access links. However, due to the defects in load balancing strategy, the load is not uniformly shared and the utilization of physical links is low, which makes the access links the bottleneck of the high-performance of the core network. In this paper, a link aggregation approach for multiple physical links was proposed. The approach does not require same rate at eh device ports during the aggregation. It can effectively expand the logical bandwidth of the entire access links. Since the method only groups the IP addresses in the access load scheduler, the implementation is easy, but it also caused the load being successively allocated to the same physical access link. When there are more access links, the time spent for the link aggregation to reach a stable working condition will become longer. This is an area that needs further investigations for a solution.

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