Designing Reliable Virtual Service Network over Open Substrate Infrastructure

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Abstract**:** *This paper addresses the designing reliable virtual service network over the open substrate infrastructures; which is envisioned as the future Internet. In this environment, VSN can be allocated across multiple substrates owned by various infrastructure providers and virtual network providers are expected to have very limited information of the underlying substrate. Hence, it is highly possible that the multiple virtual resources can be allocated onto a common substrate resource at the underlying layer without notice. As consequence, if that common component fails, severe failures will occur at the virtual network layer. However, current reliability design approaches only focus on the substrate networks owned by a single administrative entity. In addition, the existing recovery mechanisms will not be effective when multiple concurrent failures occur. In our study, we propose geographically diversified substrate resources allocation approach in order to minimize the simultaneous failures of multiple virtual resources that can significantly impact to the virtual service network reliability. To do so, we propose the geolocation META data to determine the shared components among the underlying substrates owned by different providers. We also present a heuristic reliable virtual service network design algorithm based on the proposed META data. Through the comparative analysis, the outcome indicates that our proposed method is effective for multi-layer open substrate infrastructure.*

Keywords: *reliable VSN, simultaneous failures, virtual network allocation, virtual service network, VSN*

1. Introduction

Recently, the demand of network-based applications has escalated and the virtual service network is a promising solution. In virtual service network (VSN) environment, infrastructure providers (InPs) lease their physical resources and service providers (SPs) will host customized end-to-end services by effectively sharing and utilizing the network resources provided by InP. This is technically achieved by network virtualization which allocates physical resources from the physical substrate to the virtual nodes and links dynamically.

As VSN popularity increases, the process of allocating virtual resources onto physical resources in a reliable manner becomes one of the major concerns since failures in the physical substrate can disconnect multiple VSNs. Many researches have been conducted in this area by focusing on the generic virtual network environment which is closed, meaning that allocating VSN upon a single substrate or substrates owned by a single administrative entity. However, in the future, the provisioning of VSN will rely on multiple substrates which are owned by different administrative entities, creating open substrate infrastructure environment. Figure 1 presents an example of VSN allocating upon two different substrate environments.

This next-generation open substrates infrastructure introduces new challenges to VSN reliability. One of the characteristics of open substrate infrastructure is isolation. With the close infrastructure, both the detailed information such as their relationship with other entities, network topology and resource capacity etc. are visible to service providers meanwhile in the open substrates infrastructure, there is no explicit information sharing among all of the anticipated entities. As consequence, open substrate can have multi-layered multi-resource sharing mechanism. In the open substrate infrastructure, the capacity of a substrate resource may come from another virtual or physical resource or combination of both from the underlying layers. And it is also possible that substrate resources which are claimed to be owned by different InPs can physically share or pass through the common component at the underlying network layer. As a result, any failure (e.g. hardware error) at the common substrate component will produce the simultaneous or cascaded failures of multiple resources at the upper level VSN. Another reason of simultaneous VSN failures is the occurrence of regional failure in the substrate network (e.g. disaster failure or power outage). Nonetheless, simultaneous failures will produce massive disruption and will substantially impact to the VSN reliability. Thus, in our study, we assume that the highest reliability means the lowest simultaneous failures which is the main objective of this paper.

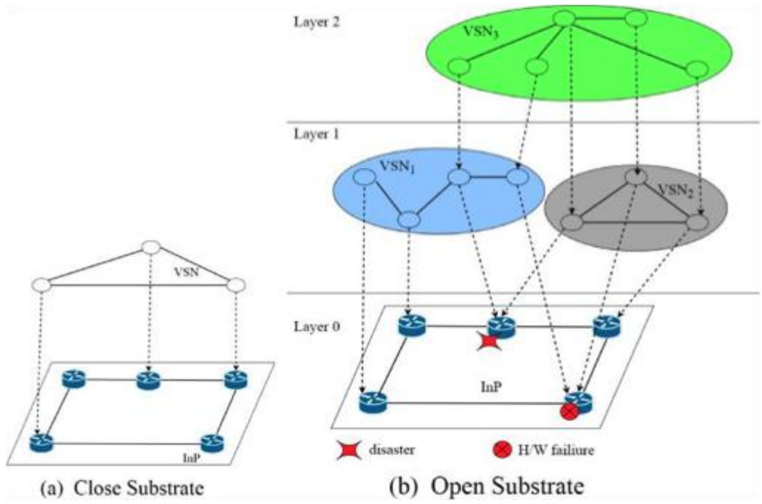

Fig. 1: Close Vs Open Substrate

Most of the existing reliable VSN design approaches rely on recovery/rerouting mechanisms with over-provision of physical capacity for deterministic failure models. However, their design algorithms require full knowledge about the underlying substrate which is impractical in our environment. Additionally, compared with the close environment, the later may require larger investment for backup capacity provisioning and will not be economically sustainable in practice. Moreover, reliability in open substrate environment is still unexplored area and to the best of our knowledge, this is the first study addressing reliable virtual network solution over open substrate infrastructures.

In this paper, in order to design high reliable VSN upon open substrates infrastructure, we propose geographically diversified VSN to substrate resource allocation which can minimize the simultaneous failures at the VSN layer. To achieve this, our proposal has two contributions. Firstly, we propose resource geolocation META data in order to identify the relationship of substrate resources owned by different InPs. Secondly, we propose a heuristic diversified resource allocation algorithm by using the proposed META data. The outline of paper is as follows. Section 2 described existing works. Section 3 explain resource diversification framework. Section 4 formulates the problem statement and network models. In section 5, the proposed algorithms are discussed. Finally, section 6 analyzes some initial evaluation.

2. Related Work

This section gives a brief explanation about the major existing proposals for the reliable VSN allocation and design.

To solve the reliable virtual network allocation, the existing researches mainly use protection and restoration mechanisms. [1] proposed a hybrid strategy heuristic algorithm by utilizing a preserved quota for backup substrate link. In order to reduce the redundant resource, [2] proposed a method that nodes and links are backed up in different areas for the virtual network, which requires virtual nodes to transmit the current states to the backup nodes and exacerbates substrate network resources consumption. [3] proposed an optimizing redundancy pool to allocate backup resources to multiple virtual networks dynamically, which can reduce redundant resources consumption of the substrate network. Unlike the protection mechanism, [4] proposed a topology-awareness and reoptimization mechanism based on node migration and link remapping, which does not provide virtual networks with redundancies. However, all of the existing approaches only focused on the general VSN allocation for reliability in generic VSN scenarios/close system by assuming with complete substrate information. Furthermore, simultaneous failure events consisting of multiple nodes and links are not addressed in any approach.

3. Resource Diversification Framework for Reliable VSN

Inside open substrate infrastructure, simultaneous failures are undeterministic and cause major impact to the VSN reliability. Hence, our aim is how to allocate VSN onto substrate components with the minimum possibility of the simultaneous VSN failures. To achieve this, we introduce the resource diversification framework to avoid the allocation of multiple virtual resources onto the same substrate resource which is the major cause of the simultaneous failures as previously mentioned. Resource diversification means that the virtual resources from a single VSN will be allocated across different substrate network resources with the assumption that there is no common component shared between these substrate resources at the underlying layers.

The baseline approach is the InP-wise diversification i.e. virtual resources are allocated to substrate resources owned by different infrastructure providers. It is the straightforward since the granularity of InP information is coarse-grained and it is easy to obtain. However, if there is the overlapped substrate resources among different substrate at the underlying layer, diversified based on InP will become insufficient and the desired reliability will not be achieved.

In this case, diversify based on physical component ID (e.g. hardware ID) can be the most appropriate. Every networking device has the unique hardware ID. During the VSN allocation process, VSN manager can learn that information to avoid the sharing the same physical device. However, hardware ID is coarse-grained and impractical to acquire in the multi-layer open substrate infrastructure.

Moreover, both of the above solutions are lack of standardization since there is no standardized structure for InP names. For hardware ID, various information are possible such as PC serial number, CPU ID, MAC address or router ID or IP address etc. With the standardized structure, the information from any network layer (i.e. intermediate VSN or physical substrate) can be aggregated or integrated and transferred to the target VSN layer.

Another solution is diversification based on geolocation where the substrate resources exist. In this case, there are multiple options that can be used as geolocation. Firstly, we can diversify based on resource GIS information. For this method, GIS information is easy to obtain and has standardization yet the information is still coarse-grained. Here, the granularity level of information has direct impact to the efficiency of the diversified allocation since in the open substrate environment, substrate information is scarce and the acquired information can be incomplete or inaccurate. Instead of absolute geolocation, relative geolocation can be used to solve this issue.

Another consideration for diversification is failure reasoning since the intention of the proposed diversifying approach is to reduce the simultaneous failures. There are several types of substrate failures that can lead to the simultaneous virtual failures and we need to make sure that our proposed method can be applicable to most of the failure scenarios. For instance, InP-wise diversification and hardware ID-based diversification are only suitable to the limited failure causes. That is, InP-wised approach is suitable for man-made disaster scenario such as Electromagnetic Pulse (EMP) attack or DOS attack and hardware ID-based approach is mostly applicable to the network with hardware failures. On the other hand, geolocation diversification can be used to deduced most of the simultaneous failure scenarios such as hardware failure at a particular location or regional failures (may or may not from disasters).

3.1 Geolocation META Data for Resource Diversification

In our study, we use relative geolocation information for diversified VSN to substrate resource allocation. We call this information as geolocation META data or geofence. A geofence is a finite geographic boundaries or the smallest enclosing box for the convex hull of the interested objects. Typically, a geofence can be any shape. A particular example of the geofence is the minimum bounding region (MBR) which boundary is represented by two points (upper let and lower right) that cover the objects inside MBR. In our system, geofences of the network components (i.e. nodes and links) are constructed as follows.

Node geofence: A node geofence is constructed by expanding the center point coordinates of the given GPS coordinates into a circular perimeter with the predefined node radius R_n. The radius R_n is the adjustable parameter based on the failure characteristics of the geolocation of the node. For instance, the radius R of a node located in the significant hurricane region can be defined according to the potential radius of that hurricane. Similarly, the radius of a node in a wireless network can be depended on its transmission range.

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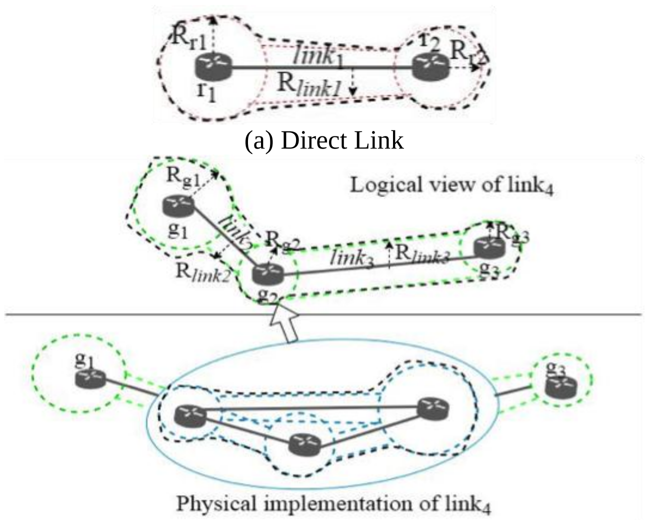
Link geofence: Link geofence can be constructed by setting the virtual perimeter that encloses source and destination nodes and the link itself. In this case, the intermediate link can either be a direct physical link between source and destination (Fig. 2a) or it can be virtual link which is provided by another infrastructure provider (Fig. 2b). For the latter case, we construct the logical geofence of the link by assuming the geofences of the underlying implementation as much as possible. Similar to R_n, we use the adapted radius of the link R_l based on the failure characteristics of the geolocation of the components along the link passes through. For instance, failure coverage region of an underground cable can be varied from a submarine cable. Likewise, failure coverage region of a link situated in the urban area can be different from a link in the rural area. Accordingly, R_l can be defined.

Figure 2 demonstrates the link geofence construction. Fig. 2a is assumed that there is a direct connection between the source and destination nodes r_1 and r_2. Accordingly, the overall geofence for the $link_{1(r1!r2)}$ is constructed as black dotted boundary. In Fig. 2b, the geofence for the virtual link $link_4$ between node g_1 and g_3 is expressed as the incomplete geofence of logical node g_2. As a result, the $link_{4(g1\rightarrow g3)}$ is defined as the black dotted boundary enclosing radii of source and destination nodes (g_1, g_3), intermediate node (g_2) and intermediate links ($link_2$, $link_3$) respectively.



(a) Direct Link

(b) Link with intermediate nodes

Fig. 2: Link geofences

3.2 Design Framework

In this section, we represent the general description of our design framework as shown Fig. 3.

Firstly, we collect the geolocation META data for the network components that we interest. In this stage, it can be simply given by infrastructure provider or can be easily collected from open-source databases or third-party GIS databases such as IPInfoDB as shown in Fig. 4. It is the responsibility of the VSN manager to collect the geolocation information of the interested substrate resources.

Since the accuracy of geofences has direct relation with our geolocation-based diversification approach, we need to prepare the accuracy of the collected geolocation META data as precise as possible. Moreover, it is possible that some infrastructure providers can mask or conceal their geolocation for the privacy and security purposes. Therefore, as the next steps, the accuracy of the collected geolocation META data can be increased by using aggregation and verification process. In data aggregation, META data for a particular network component can be obtained from various information sources such as from the owner InP, opensource GIS databases, ontologies or Internet.

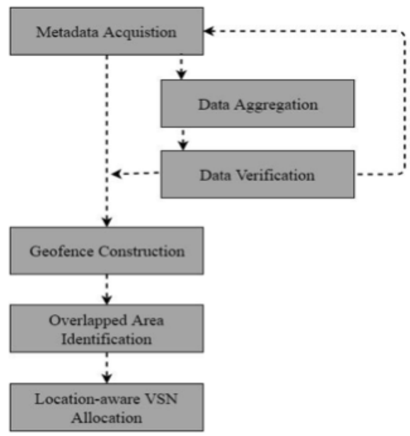


Fig. 3: Design framework

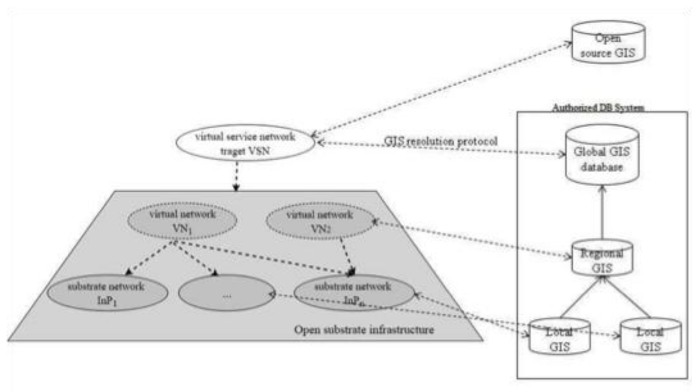


Fig. 4: Geolocation metadata acquisition

After that, collected META data is aggregated to form a complete META data. We call the META data which is collected from unauthorized data source as gossip. The initial META data is combined with the gossip by using a particular function which can be the simple addition operation or more complicated operations as shown in Equation 1. After that, aggregated META data is verified for accuracy evaluation.

$$META = f_{aggregate}(META_X, gossip) \qquad (1)$$

META data acquisition, aggregation and verification are the recursive processes. In the step 4 and 5, we identify the overlapped geolocation of the substrate components by using the geofences. Finally, our location-aware algorithm allocates the virtual resources upon minimum overlapped substrate resources.

4. Problem Statement and Network Models

In this section, VSN and open substrates model is depicted and the problem space is formulated.

4.1 Network Models

The problem we consider consists of two types of networks: VSN and substrate and we use superscript to distinguish between them.

Virtual service network: A virtual network topology, $G^V = \{n_1,\ldots,n_j, l_1,\ldots,l_k\}$ is modeled as the sets of virtual nodes and links. Each virtual node $n_j \in N^V$ is associated with its CPU capacity requirement $C(n_j^V)$ and each virtual link $l_{ij}^V = (n_i, n_j) \in L^V$ has a bandwidth requirement of $C(l_{ij}^V)$.

Substrate network: In our approach, we model the substrate network G^S as the same set of G^V i.e. the set of virtual resources that the substrate network can provide. Formally, $G^S = \{n_1^S,\ldots, n_j^S, l_1^S,\ldots, l_k^S\}$ where n_j^S, l_k^S can be 1 if the substrate network can provide that requested virtual resource, otherwise 0. Moreover, each substrate node and link is given together $C(n_j^S)$; $n_j \in N^S$ and $C(l_j^S)$; $l_j \in L^S$ with their cost and META data attributes.

Open substrate infrastructure: An open substrate infrastructure is the set of the multiple substrate networks managed by different InPs. We denote an open substrate infrastructure as the set $INP = \{ G_1^S, G_2^S, \ldots, G_m^S \}$. From VSN perspective, they all together can be seen as the pool of available substrate resources.

Geolocation META data of node and link: The formal description of the node geolocation is described by its META data attribute $\forall n \in N : META_n = \Gamma_n(center\_loc_{lat,long}, R_n)$, where Γ_n denotes geofence of the node n. Here, we omit heading and speed of the geolocation. Geolocation for the link from source node *s* to destination node *t* is described by $\forall l_{s\to t} \in L : META_l = \Gamma_l(\Gamma_s, \Gamma_t, \Gamma_{N'}, \Gamma_{L'})$ where *N'* and *L'* are the set of intermediate nodes and links.

4.2 Problem Formulation

By given the required VSN design G_V and a open substrate infrastructure INP, our intention is that we will find a particular diversification allocation of VSN across open substrate with the possibility of simultaneous virtual failures in terms of overlapped geolocation area is minimized such that

$$\text{Minimize} \qquad q_{M:VSN\to InP} = \square_{n,l\in N,L}(G_n, G_l) \tag{2}$$

Allocation and Splitting cost for Node and Link

Besides, when the substrate networks host a VSN, the resource allocation cost will be occurred. In addition, for efficiency and flexibility, the allocation approach should support the splitting of virtual links over multiple substrate paths. Similarly, virtual node splitting occurs when optimization is considered. In both cases, there will be additional cost induced for node and link splitting process. From the business model perspective, the cost for the VSN to substrate allocation should be minimum such that

$$\text{Minimize} \qquad Y_{M:VSN\to InP} = \sum_{n'\in N^{V\to S}} [C(n') + split(n')] + \sum_{l'\in L^{V\to S}} [C(l') + split(l')] \tag{3}$$

Objective function and constraints

In fact, the objective function of our proposed method is to achieve the VSN to substrate allocation with minimum share components and minimum cost of allocation. However, there is no such solution that could achieve both objectives. Thus, we define our objective function of virtual to substrate allocation as multi-objectives function such as

$$\mu_1.\ \min \theta + \mu_2.\ \min \Psi \tag{4}$$

5. Resource Diversification Algorithms

5.1 Geolocation Resource Diversification Algorithm

A simple way to solve the multi-objectives optimization problem is to treat each problem as the sub-optimization problem by using the other objective as constraints. This section describes the proposed algorithms to find virtual to substrate resource allocation which achieved multiple objectives.

1) Geolocation Diversification Algorithm: As the objective, we consider minimum overlapped component θ or minimum cost constraint ψ.

Name: θ/ψ Algorithm
Given: G_V,INP
Output: min θ_M/min ψ_M

- Step 1: One virtual node is chosen as the seed node using random-based or priority-based approach. For instance, node degree and reliability requirement can be seen as priority factor. Calculate node allocation cost ψ. A virtual node can be splitted into m child nodes, whose CPU demand is mapped onto m substrate nodes as well as their flow demand.

- Step 2: A virtual link connected with the seed node (i.e. source node) will be allocated to the substrate link with min $\theta(\Gamma_n, \Gamma_l)$ or min $\psi(\Gamma_n, \Gamma_l)$. For link-splitting, each virtual link is allocated as *p* substrate paths in which the sum of the flow capacity of splitted links are the same as the original virtual link. The step iterates for all connected links. Summarize it with the cost from the previous steps.
- Step 3: The virtual node connected with the allocated virtual link (i.e. destination node) will be allocated to substrate node with min $\theta(\Gamma_l, \Gamma_n)$ or $\psi(\Gamma_l, \Gamma_n)$. The step iterates for all connected nodes. Summarize it with the cost from the previous steps.
- Step 4: Repeat step 2 and 3 until either all VSN resources are allocated.
- Step 5: The algorithm will stop if all VSN resources are allocated. Otherwise, the algorithm will be iterated again by choosing different seed node or varying the cost constraint input.

As the result, we will receive the VSN to substrate resource allocation with minimum overlapped resource. To illustrate the algorithm steps. Fig. 5 is shown.

2) Hybrid Algorithm: We combine both objectives by using θ/ψ ratio such that

$$q/\Upsilon = \lim_{T \to a} \frac{\sum^{T}_{t=0} q_M}{\sum^{T}_{t=0} y_M} \tag{5}$$

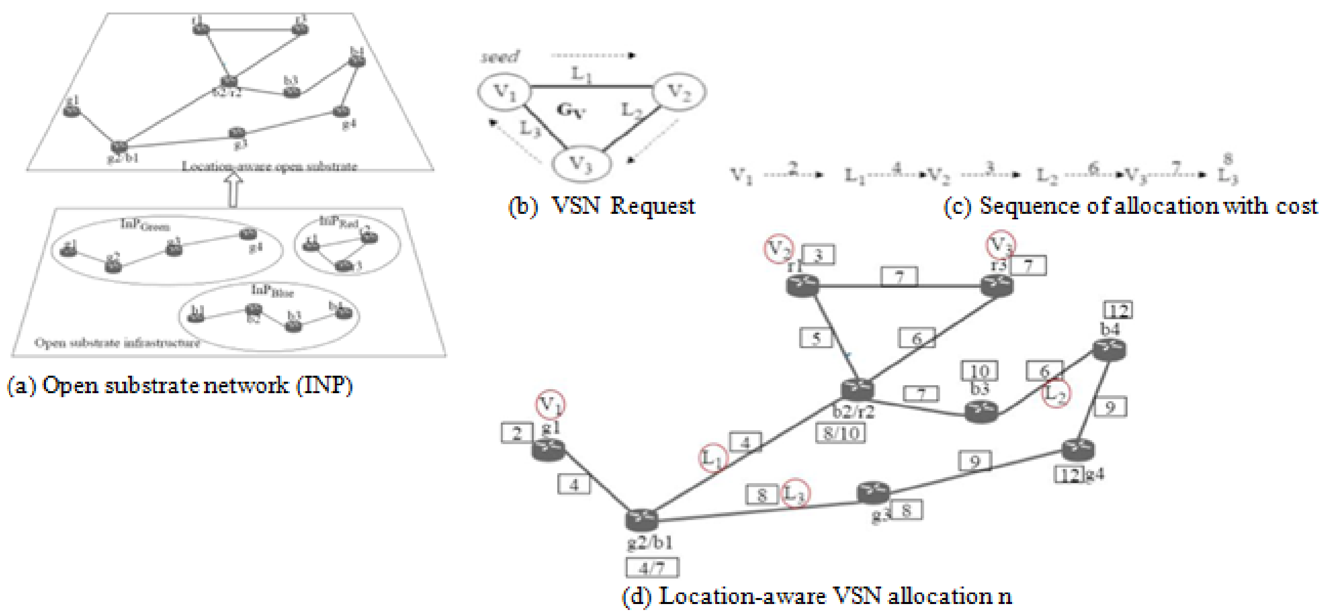


Fig. 5 Location aware virtual to substrate allocation with min θ objective

6. Evaluation and Conclusion

As the initial study, we will verify the effectiveness of our proposed method by using the comparative analysis. This section discusses the key characteristics of the proposed META data with the alternatives.

Easy to obtain: META data acquisition at target VSN should be straightforward with minimum complexity. In our proposed method, geolocation META data can be given or can be collected easily from the third-party information sources such as Google Maps.

Information granularity: One of the characteristics of VSN is isolation i.e. there is no explicit information sharing among all of the anticipated entities. So in this environment, the scale or level of detail present in our

META data also need to be considered. Moreover, information granularity relates with easy to obtain characteristics. Nonetheless, the proposed META data must be applicable with incomplete or inaccurate information and can provide acceptable accuracy.

Data aggregation: Firstly, META data which are collected from different entities are required to be integrated as a single META data without difficulty. Secondly, we need to prepare the META data as precise as possible since our reliability is directly related with META data accuracy.

Reasoning to VSN failures: META data can be used to deduced any virtual network failures scenarios.

Figure 6 illustrates the comparative analysis of our META data with the other optional META data.

As conclusion, our approach is effective for reliable virtual network allocation over open substrate infrastructures.

7. References

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META	Description	Granularity	Data acquisition	Data aggregation	Failure type reasoning		Failure sources
					Single failure	Regional failure	
InP ID	▪ e.g. company name ▪ Different ID means different infrastructure provider ▪ There may be shared resources among different owner ID	Coarse-grained	Easy	✕	✕	✓	▪Disaster ▪Security attack
HW ID	▪ e.g. CPU ID, MAC addr, router ID, IP address etc. ▪ No relationship between IDs	Fine-grained	Difficult	✕	✓	✕	▪ HW failure
Geolocation	▪ e.g. GIS coordinate ▪ the closer location means that resources can fail simultaneously	Fine-grained	Medium	✓	✓	✓	▪ Disaster ▪ Security attack ▪ Power outage ▪ HW failure

Fig. 6: META data characteristics comparison