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System Performance Assessment and Sizing for Cloud-based Data Backup

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Abstract: It is a mandatory issue for enterprise to protect data even in the case of wide area disasters. The enterprise data must be backed up at remote locations. Cloud service is an appropriate solution for the target of remote backup because it guarantees its reliability by duplicating data. In order to control the risk of data loss, performance design and monitoring for data backup system is important. The performance of remote data backup should be managed by recovery point, which is the time difference between the time of system failure and the time to be recoverable. The performance indicator for recovery point is RPO (Recovery Point Objective). In this research, we propose a method of performance assessment for cloud-based remote data backup system. This method makes it possible to determine whether the system performance achieves RPO or not. And it is also necessary to resize backup system for the alignment to performance objective. Therefore, we have defined a simulation formula to calculate adaptive system size that achieves RPO and minimizes system resources. We conducted a data backup experiment and obtained a result that the gap between the experiment and simulation of recovery point at the peak of workload cloud be less than a minimum time unit.

Keywords: Data Backup, Cloud, RPO

1. Introduction

1.1 The Significance of Data Protection

Today, enterprise IT system is an essential foundation for business operations. IT system generates large amounts of data, and it has been increasing steadily [1]. There are also many attempts to discover new values from the analytics of big data such as digital map, images and enterprise business record [2][3][4]. So, data itself is recognized as a valuable asset [5][6]. As a result of this trend, the data loss causes enormous damage to enterprise not only for the reason of the loss of business opportunities but also for losing customer's trust and social credibility [7]. This is why data protection is one of the most important tasks for enterprise IT operation, and various solutions have been deployed [8][9][10].

There are a variety of data protection methods depending on its importance or IT system implementation. In order to protect significantly important data, not only local backup [11] but countermeasures against site scale damage such as terrorism and natural disasters are required. Disaster recovery has been deployed to confront these threats. It replicates data to the sites that are geographically separated and implemented with an alternative IT system. Even in case of a disaster, the system keeps running on the alternative site [12].

Cloud service is also an effective solution as a target of remote data backup. It is possible to reduce the cost of operating backup datacenter by company itself. In general, data reliability is ensured by duplication or triplication in the cloud, so it can be a suitable solution for the storage of remote data backup.

1.2 Data Protection Performance Index

It is necessary for data backup system to set an appropriate performance target according to the requirement of business operations and important level of data [9]. The performance indices for data protection are defined by Recovery Point Objective (RPO) and Recovery Time Objective (RTO). RPO is an index to manage the risk of data loss. It is defined as the difference between the time at which a failure or disaster happened and the time at which data can be recovered retroactively. As an example, if RPO is '60 seconds', it is required to be able to recover all data recorded up to 60 seconds before the time of failure. On the other hand, RTO is a performance index targeting recovery time after the time of disaster.

In this research, we propose a performance assessment method of data backup system focusing on RPO.

1.3 System Sizing

It is important to adjust the amount of system resources in accordance with workloads. System resources must be added in order to achieve RPO if performance is insufficient for the workloads. Conversely, if the performance is over than the target, system operation cost can be reduced by downsizing. For system sizing, it is a problem to estimate the amount of appropriate system resource that achieves both performance target and cost reduction.

1.4 Objective

The primary objective of this research is to define a method to judge whether the data backup system achieves its performance objective, RPO. And we try to verify its effectiveness through the experiments.

The second object of this study is resizing remote data backup system. The operators will be able to reconsider the appropriate system size in accordance with the result of above performance evaluation. As shown in Figure 1, if the system does not achieve RPO, they should increase system resource. Otherwise, if the performance is excessive, some resources should be discarded to reduce system cost. We define a method to calculate system size

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that accurately estimates the amount of resources necessary to achieve RPO.

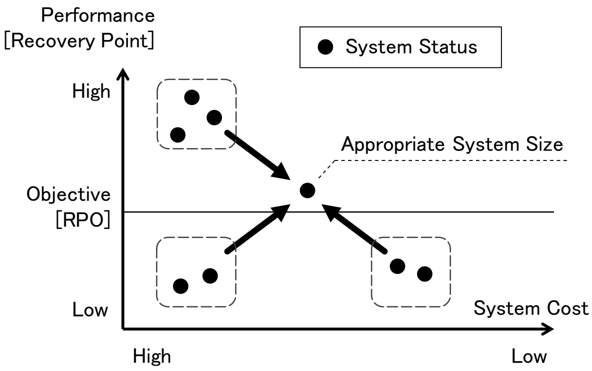

Figure 1 The Objective of This Research

2. Cloud-based Data Backup System

2.1 Cloud Storage Gateway

Cloud Storage gateway service is available to back up data generated on-premises site. For example, Amazon Web Services (AWS) releases AWS Storage Gateway service [21]. As described in Figure 2, this is a gateway function installed on the on-premises side that transfers data sequentially to online cloud storage, AWS S3. There are two operation mode, "cached volume mode" in which primary data is placed in cloud, and "stored volume mode" in which primary data is placed on-premises. In this research, we focuses on cached volume architecture that is smaller delay in data transfer.

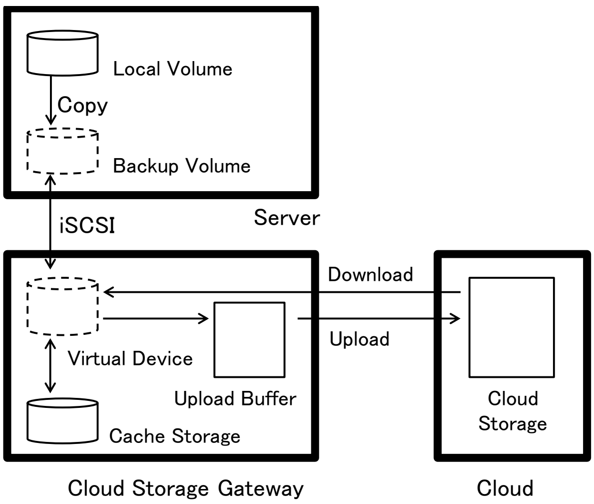

Figure 2 Cloud-based Data Backup System

In the cached volume mode, the gateway device supplies storage resources originally deployed on cloud as a virtual device. A server running on-premises connects to this virtual device via iSCSI protocol and applies it for backup volume. The application data generated on server is recorded in local volume, and it is copied to backup volume by functions such as storage mirroring or backup software.

The gateway records data written in virtual device into cache storage, and transfers them to cloud. An upload buffer is used as a temporary storage for data to be transferred. The standby data stored in upload buffer is transferred to cloud via internet or a dedicated communication line.

2.2 System Performance of Data Backup

Since the cloud gateway is asynchronously transfers data that is temporarily stored in the upload buffer, there is a possibility that a part of data is lost at the time of disaster. The "recovery point" is a parameter that represents a gap between the time of disaster and the time at which data recovery is possible. In order to guarantee system performance, the recovery point must be shorter than RPO.

As illustrated in Figure 3, in case where the data written by server is recorded at 12:00 and reaches cloud at 12:05 after temporarily stored in upload buffer or communication delay, the recovery point at 12:05 is "5 minutes". At this point, if a failure occurs on the on-premises site, all data recorded after 12:00 is lost because it has not been transferred yet. If RPO is longer than 5 minutes, the performance target has not been achieved, so that some actions such as system resizing are required.

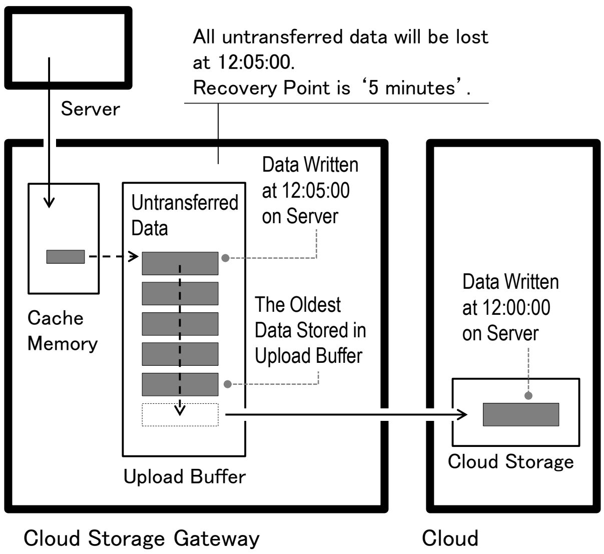

Figure 3 Recovery Point

2.3 Issue of Cloud-based Data Backup System Management

Therefore, in order to operate data backup system, it is required to monitor recovery point and to check whether it has achieved RPO. However, in general, system monitoring function implemented on cloud services does not support a monitoring metrics that corresponds to recovery point. In an example of Cloudwatch which is the monitoring service of AWS, the metric corresponding to recovery point, or transfer delay time is not supported. For this reason, it is an objective of this research to make it possible to calculate recovery point by using other metrics provided by standard monitoring services that does not require some special implementation.

Also, if it is judged the system performance is too high or too low to guarantee RPO, system configuration should be properly reconsidered. In order to achieve both the performance objective and the cost minimization, the amount of system resources such as the network bandwidth that determines the data transfer performance or the storage capacity of upload buffer should be adjusted for appropriate size. This is second task of this research to estimate appropriate system resource amount by simulation.

2.4 Solution Approach

We solve these problems by following approach.

(1) Cloud-based Data Backup System Modeling

In order to simulate system condition including recovery point, we define an abstract model of backup system.

(2) Performance Assessment by Recovery Point Calculation

In order to evaluate backup system performance, a recovery point calculation procedure is defined. The recovery point is calculated by the inputs of written data amount and untransferred data amount. It is possible to judge if system performance objective is achieved or not by checking whether this recovery point is shorter than RPO.

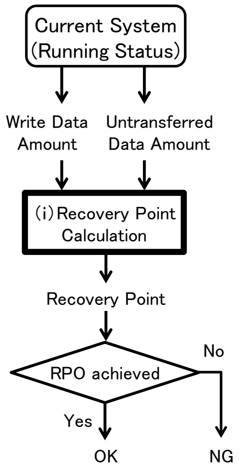

Figure 4 A Flowchart for Backup Performance Assessment

(3) System Sizing by Performance Simulation

In order to estimate an appropriate amount of system resources, we define a simulation process to calculate recovery point for a variety of assumed system. As described in Figure 5, based on this simulation, the best system configuration is derived that achieves RPO and minimizes cost.

The recovery point calculation procedure of (2) is applied to each system assumptions. The past workload records are applied as write data amount that is one of the inputs of calculation formula as defined in Figure 4. As described in Figure 6, another input is the amount of untransferred data, which is also calculated by a formula (ii) with the input of write data amount and assumed system resource configuration parameters.

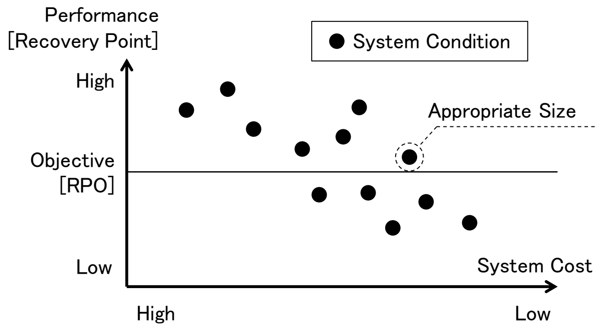

Figure 5 A Concept to Determine Appropriate System Size

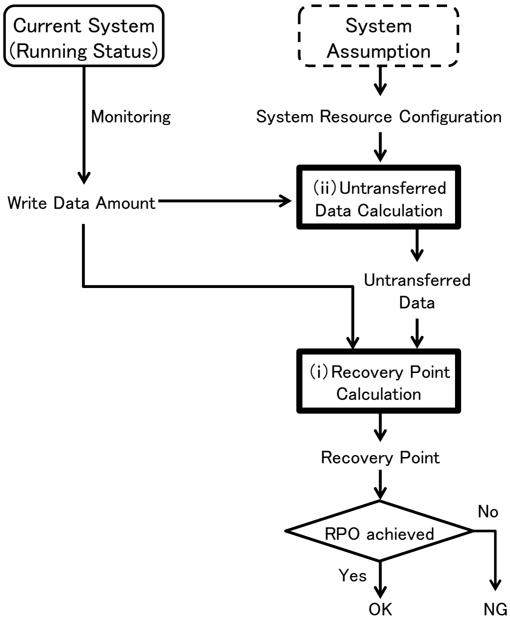

Figure 6 A Flowchart for Backup Performance Simulation

3. System Performance Assessment

3.1 System Modeling

We define a cloud backup system model in order to simulate the behavior of cloud storage gateway. This model is an abstract representation of system configuration and data transfer process. And it is used for the prediction of the system performance.

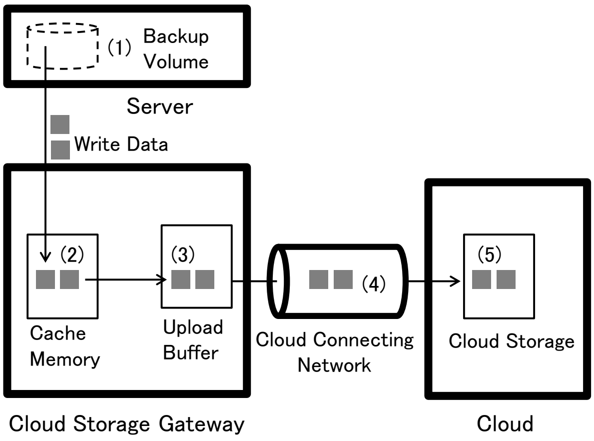

Figure 7 Cloud-based Data Backup System Model

Although there are various components in cloud and cloud-based backup system, in this research, we pick up parts necessary for calculating recovery point, and describe a system architecture only with them. As shown in Figure 7, there are a cloud storage gateway installed on-premises site, cloud service that provides online storage, and they are connected by a cloud connecting network. A storage gateway offers a backup volume, cache memory and an upload buffer. A backup volume is a storage resource which is writable from server. A cache memory is simply used for temporarily storing data written to the backup volume. An upload buffer is also a temporary storage that is used only for data to be transferred to cloud. Those storage components can be implemented by a general medium such as volatile memory, flash memory or a hard disk drive. Cloud service delivers online storage for the backup data pool.

Next, backup procedure with this system model is defined. In this operation, storage gateway stores data written on backup volume (step 1) into cache memory (step 2). Thereafter, cached data are copied to the upload buffer in time series (step 3) and sent to cloud via cloud connecting network with write order (step 4). In cloud, received data is stored in the local storage (step 5).

According to this system evaluation model, the gap between the time at which data is written and stored in cache (step 2), and the time at which data is transferred and stored in cloud (step 5) corresponds to recovery point.

3.2 Recovery Point Calculation Method

As described in Figure 4, in this research, we propose a method to calculate recovery point from an input of untransferred data that is pooled in the upload buffer. Further, as illustrated in Figure 3, we paid an attention to the fact that the time of oldest write data in the untransferred data approximates the time of latest data recorded in cloud. Among the untransferred data, the oldest data itself cannot be restored, however the data written up to the immediately preceding time can be recovered because it has already been transferred to cloud. Therefore, in order to detect recovery point, we try to find a written time of the oldest data among the untransferred data stored in upload buffer.

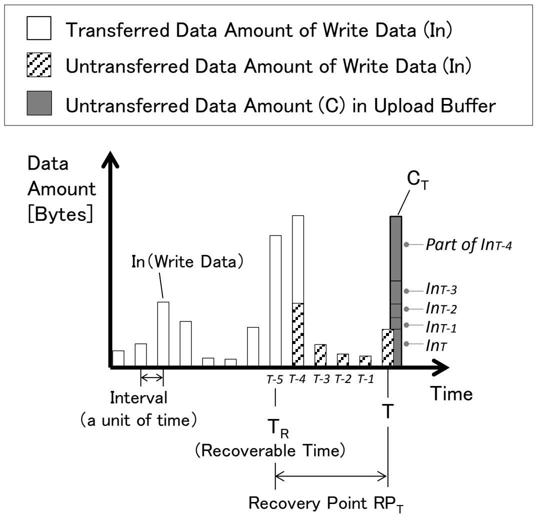

Figure 8 A Method of Recovery Point Counting

We define a formula in order to find the oldest data. There are two types of time series data for the inputs of this formula, untransferred data C and the amount of written data In. The write time of the oldest data coincides with the time at which the value obtained by cumulating the amount of written data In reaches the untransferred data amount C_T by tracing backward from time T. That is, the time at which cumulative value of hatched portion in Figure 8 reaches C_T at $T\text{-}4$, then the immediately preceding time $T\text{-}5$ is the recoverable time T_R. Recovery point RP_T is the difference between time T and T_R. These procedures are formulated as follows.

$$RP_T = T - T_R = \begin{cases} 0, & C_T = 0 \\ (n+1) \times \text{Interval}, & C_T > 0 \end{cases}$$

Here, n is the smallest integer satisfying the following.

$$C_T \leq \sum_{i=0}^{n} In_{T-i}$$

The static parameter Interval is a unit of time, which corresponds to sampling interval of time series transition parameter such as In and C. And n is the number of times the write data amount In has been accumulated backward from the time T, and immediately preceding time is the recoverable time T_R.

3.3 Performance Assessment for Cloud-based Data Backup

With the verification result of recovery point RP_T calculated according to the above procedure, it is possible to judge whether RPO is achieved or not. If the maximum value of recovery point during the time range of verification is longer than RPO, the performance target has not been reached, ant it is desirable to solve this problem by the reinforcement of system resources. On the contrary, in the case that it is significantly shorter than RPO, it is expected to lower the system operation cost by discarding some resources.

4. System Sizing for Cloud-based Data Backup

4.1 Simulation for the Amount of Buffered Data

As described in 2.4, we define a method to calculate recovery point for some assumptions of system configuration. As illustrated in Figure 4, the amount of untransferred data *C* is input to this calculation. Therefore, in this section, we define a formula to simulate the amount of untransferred data *C*.

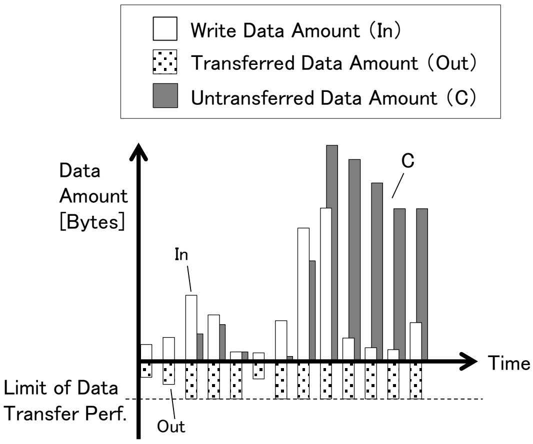

Figure 9 An Example of Untransferred Data Accumulation

The amount of untransferred data C_T can be calculated by the following equation. Here, it is denoted that the amount of written data to backup volume at time *T* by In_T, and the amount of transferred data to cloud by Out_T.

$$C_T = C_{T-1} + In_T - Out_T$$

This equation means that the untransferred data amount C_T increases in case that the amount of transferred data Out_T, which is dependent on the network performance of cloud storage gateway and cloud connecting network, is insufficient with respect to written data amount In_T. Here, C_{T-1} represents the untransferred data amount at the time *T-1* that is one time before the time *T*.

The amount of transferred data Out_T is limited by the performance of data transfer if it is insufficient for the amount of data to be transferred at time *T*. In the system model defined in section 3, it is assumed that the data written to storage gateway is stored in upload buffer for a certain period of time and then sent to cloud at once. If this standby time is defined as a static value *D*, the amount of data to be transferred at time *T* corresponds to the untransferred data amount at the time *T-D*. On the other hand, the transfer performance matches the lower one of the IO performance of upload buffer P_{Buffer_IO} and network performance for cloud data transfer $P_{Network}$. Under the above conditions, the transfer data amount Out_T is formulated as follows.

$$Out_T = \min\{C_{T-D}, P_{Buffer\_IO}, P_{Network}\}$$

There is a possibility to improve accuracy to calculate transfer data amount Out_T with the consideration of the effect of data compression. If there is overwrite on the same address among the data staying in upload buffer, it is possible to increase the transfer efficiency by sending only the latest data instead of transmitting all data. Assuming that the compression rate of data to be transferred at time *T* is represented as Z_T, the data amount before compression that can be transferred coincides with the value obtained by dividing the performance limit by Z_T.

4.2 Appropriate System Size Detection

A Simulation process above makes it possible to calculate the amount of untransferred data for variously assumed system configuration and to predict recovery point for each of them. There must be the best assumption case among them that achieves RPO with lowest cost. In this study, the bandwidth of cloud connecting network is picked up for a variable of cloud-based backup system simulation. The amount of untransferred data increases or decreases according to the size of data transfer bandwidth. Therefore, the storage capacity of upload buffer should be also considered as a factor for determining system cost.

The total cost is a sum of the cost of components that comprises entire system. However, a variable part of the system cost in this study can be calculated by the following equation.

$$Cost_{Variable} = Cost_{Network} + Cost_{UploadBufferSize}$$

An appropriate system size is the case that achieves RPO and minimizes the system cost calculated by this equation.

5. Evaluation

5.1 Experiment of System Performance Assessment

(1) Experiment Conditions

We have conducted an experiment to evaluate the effectiveness of this study. We reproduced the workload from the actual enterprise IT system experience. As shown in Figure 10, this is a time-series transition of the written data amount measured with the sampling rate of 5 minutes interval. According to the method of Figure 8, recovery point is calculated with the unit of time interval, so the result in this experiment is calculated by a unit of 5 minutes. The data production system implemented on-premises site was connected to internet. Amazon Web Services is used for the cloud that is a target of data transfer. And AWS Storage Gateway was installed and set to cached volume mode. The storage gateway is implemented by a virtual server, and upload buffer is implemented with hard disk drives. Also, in order to simulate the upper limit of network bandwidth, the output performance parameter of storage gateway was tuned to 10Mbps.

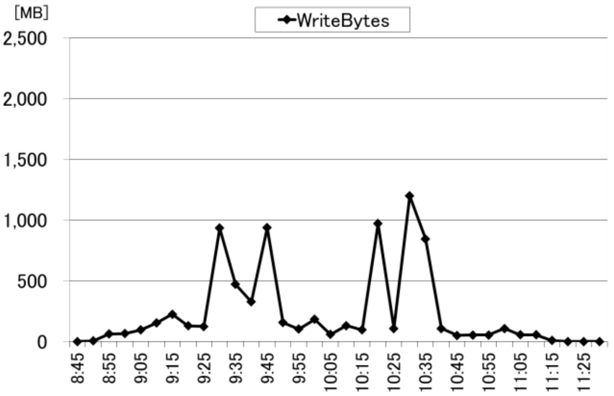

Figure 10　Write Data Amount

Table 1 shows the correspondence between metrics in Cloudwatch which is system monitoring service of AWS and parameters defined in this research.

Table 1　Parameter Relationship

#	Performance Metric	This Research	AWS Cloudwatch
1	Write Data Amount	*In*	*WriteBytes*
2	Transferred Data Amount	*Out*	*CloudBytesUploaded*
3	Untransferred Data Amount	*C*	*QueuedWrites*

(2)　**Results**

The experimental results are shown in Figure 11. The *CloudBytesUploaded* parameter corresponding to the transfer data amount *Out* has been monitored less than 375MB per 5 minutes. This means that the upper limit of data transfer performance of storage gateway was 10Mbps that equals to 375MB/5min. The measurement of *QueuedWrites* parameter that corresponds to untransferred data amount *C* shows how untransferred data is accumulated in upload buffer due to the write data amount *WriteBytes* exceeding the upper limit of transfer performance. In this experiment, it was measured that untransferred data exceeded 2GB at the peak of 10:35, and all of them may be lost in case of the trouble at on-premises site.

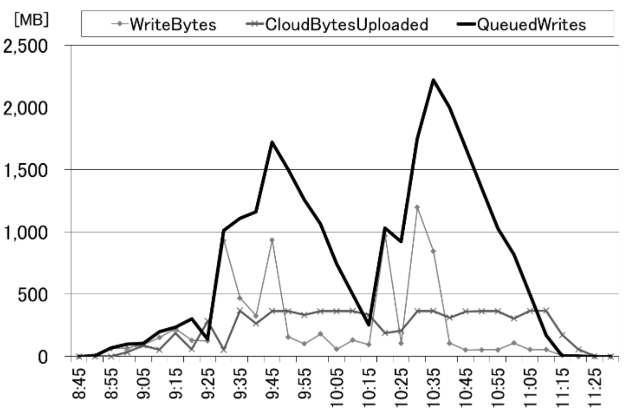

Figure 11　A Result of Storage Gateway Performance

Figure 12 shows a result of recovery point calculation. *QueuedWrites* measurement of Figure 11 was an input of the calculation. As a result, the maximum recovery point within the inspection time range was 35 minutes. In case if RPO is longer than 35 minutes, it means that system performance objective was achieved. However if it is less than 35 minutes, the performance target has not been reached, so it is necessary to review system resource.

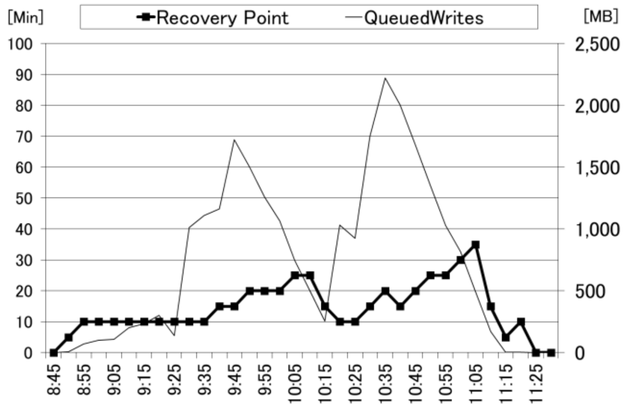

Figure 12　A Result of Recovery Point Counting

It is demonstrated that recovery point calculation method in this research is effective by these experiments.

5.2　Consideration of System Sizing

(1)　**Buffered Data Amount Simulation**

Next, we consider the system sizing procedure using this experimental data. Figure 13 shows the calculation result of untransferred data amount for some assumptions. In this condition, network bandwidth was set to 10Mbps and communication efficiency was tuned as a variable. And a static parameter *D* that is a buffer residence time, is set to 5 minutes that is a minimum unit of time. These evaluation was performed with the communication efficiency changed from 100% to 80%. As a result, the gap between measurement records and calculated value was minimum in the case that communication efficiency is 90%. In this case, the gap was only 7% at the peak time of 10:35. As shown in Figure 14, this is merely an error of 5 minutes which is the minimum unit time in terms of recovery point. In other words, 5 minutes is a minimum value of error, so we conclude that this simulation result is sufficiently accurate. With these consideration, the effectiveness of this research method is demonstrated.

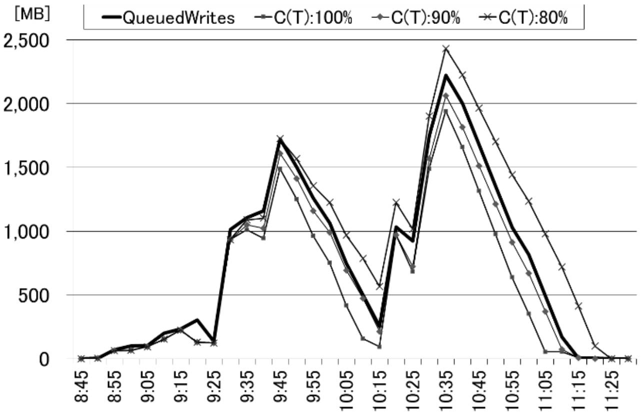

Figure 13 A Result of Non-transferred Data Simulation

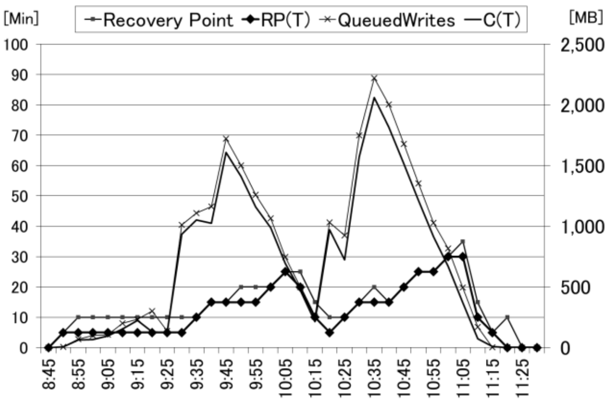

Figure 14 A Result of Recovery Point Simulation

(2) **Detection of Appropriate System Size**

Finally, in order to verify the effectiveness of system sizing method, some simulation results are shown in Figure 15. In this study, we assumed eight patterns of network bandwidth from 4Mbps to 20Mbps. Since the amount of untransferred data remaining in upload buffer is larger as the network bandwidth is smaller. This means that smaller bandwidth makes recovery point longer, so it is required to prepare a larger capacity of storage for upload buffer. In this evaluation, recovery points are calculated with the condition of 5 minutes buffer residence and 90% communication efficiency as same as consideration of section 5.2.

For example, a configuration in which the bandwidth is 10Mbps, the recovery point was calculated as 30 minutes, and the required storage capacity for upload buffer was 1.92GB as plotted in Figure 15. In this case, a variable system cost is the sum of the communication cost of 10Mpbs and the storage cost of 1.92GB. It is possible to detect appropriate system size by choosing smallest cost case among the configurations that achieve RPO.

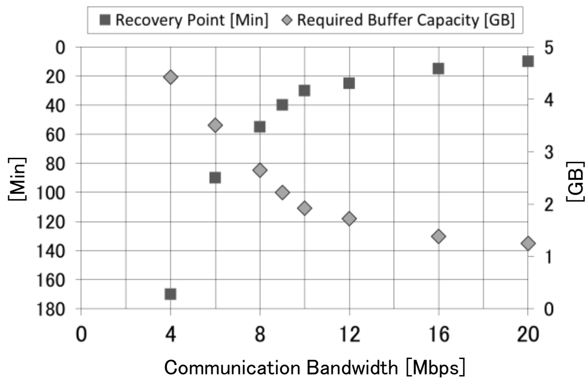

Figure 15 Performance Estimation by System Configuration

6. Next Steps

In this paper, we studied a remote backup system that transfers data from IT system installed on-premises to cloud. On the other hand, a recovery point calculation method and untransferred data amount calculation method of this research can be applied to various applications not only for data backup. For example, it is expected that a huge number of devices will be connected to network with the spread of IoT, Internet of Things [27][26]. There are types of IoT devices such as factory machines, automobiles and monitoring cameras. It is a common feature of IoT that these devices transfer its generated or collected data to a data center. In some IoT applications, the data transfer delay can be a cause of problem such as abnormal detection error or real-time failure notification error. Therefore, it is required to assess performance and optimize system size so as to achieve the data transfer performance objective. Since this research estimates performance based on the amount of written data and system resource size, it is an advantage that this procedure can be applied to general purpose data transfer systems without special implementation such as additional time stamp in network protocol. Thus, technology deployment into IoT is one of the future tasks.

In addition, although this research defined a system model by deep understanding of system architecture and behavior, it may be possible that a model can be defined by inductive approach such as machine learning if there is a sufficient amount of system activity data.

7. Related Research

Prior to this research we proposed a system assessment and sizing method for a disaster recovery that replicates data among storage systems [23][24][25]. It was not necessary to consider a retention time that is caused by the implementation of data transfer at sender side, because the remote copy function of storage system attempts to transmit the written data as soon as possible. Therefore, for the untransferred data amount calculation procedure of this research, we considered a behavior of buffering written data for a certain period of time at cloud storage gateway. With this improvement, it became possible to apply the solution to data backup system targeting cloud.

8. Conclusion

In this research, we propose a method of system performance assessment for data backup targeting cloud and a method to resize system resource. For this assessment, we defined a model of data backup system architecture and data transfer processes. This model is used to calculate recovery point in order to verify whether the system achieved RPO or not. Furthermore, we defined a simulation method to derive an appropriate system configuration that optimizes system performance and operating cost.

We have conducted an experiment using cloud service to evaluate an effectiveness of this research. In this experiment, we calculated recovery point by the input of other metrics. So that we cloud verify whether it had achieved RPO or not. Also, we succeeded to simulate system performance. The gap between simulation result and monitored value of untransferred data was only 7% that is less than an acceptable error range. With this simulation, it was possible to find appropriate system size from the eight patterns of assumptions. The next step of this research is the application to general purpose data transfer system.

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