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論文内容の要旨

Many high energy physics experiments have been searching a new physics beyond the standard model and it requires more precise detection and analyzing system than the current system. It requires many channels of the detectors, a large data size of an event, and a high rate trigger for a detector system. Since the amount of data handled in the system has increased, the required throughput for a data acquisition (DAQ) system is increased as well.

In order to satisfy the requirements, many DAQ systems adopt a distributed computer system and processes two or more events at the same time. A typical system consists of detector sub-systems, an event builder, event processors, and mass storage devices. The detector subsystem processes signals from detectors and sends the event fragment data to the event builder. The event builder collects these event fragment data from many detector sub-systems and builds completion events from it. The event data are sent to event processor. Finally the data are recorded on mass storage devices. Since an event builder communicates between many distributed detector subsystems, its communication technology is essential. Many recent DAQ systems have adopted network technologies for it, which are called network-based DAQ system. Various networks have been adopted, for example, IEEE 802.3 (Ethernet), asynchronous transfer mode (ATM), and so on. Especially Ethernet is widely used because it is very cost effective infrastructure. A network such as Ethernet is used with network protocols because a network does not have a mechanism for reliable data delivery.

Since the TCP/IP protocol suite is a standard protocol suite of standard operating systems, for example, Linux, UNIX, and so on, many systems adopt it for reliable data delivery. When we employ the standard reliable protocols such as the TCP/IP protocol suite for an event builder, we encounter a serious problem: event fragments are heading for the same destination at the same time so that data flows are congested and packets are lost in the network. The packet losses decrease transfer efficiency and induce re-transmissions for reliable data delivery. Generally the mechanics of packet losses by congestion is too complex to predict its behavior and performance. Moreover, the re-transmission mechanism makes more complex situations. In order to solve the problem, there is a method in general networks. That is called a Quality of Service (QoS). There are various methods but the main idea is to assign bandwidths of connections and special network devices are used for assigning bandwidths. There are two assignment methods: one assigns a fix bandwidth known as a constant-bit-rate (CBR) method, the other one dynamically assigns bandwidths known as a variable-bit-rate (VBR) method. If transfer rates of DAQ systems are constant, the CBR method solves the problem. Therefore, it is difficult to achieve a high efficiency with the CBR method. On the other hand, the VBR method requires additional protocols to control network devices for bandwidth assignments. Since the protocol assigns a bandwidth, it is also difficult to achieve a high efficiency because the protocol is not able to quickly control the devices.

When we design a highly efficient network, there is another problem which is packet losses by congestion. The packet losses make difficulties with prediction of transfer performance, and, then, a quantitatively network design. Since an even builder is designed for satisfying requirements of an experiment, this is a serious problem. It is rare case in general networks that many senders transmit to the same receiver at same time. Therefore, general reliable protocols are not designed for this case and we can not find a suitable protocol among standard ones. The other problem of using standard protocols is a heavy workload. If we need a high performance data transfer, we should adopt high performance hardware, for example, a high speed CPU, and so on.

In order to solve these problems, we have developed a new communication network protocol. The main idea of the new protocol is an avoiding congestion with a token passing mechanism. Since senders are controlled by the mechanism and only one sender that has a token is permitted to transmit data to a receiver, packet losses are avoided. By this mechanism, we can quantitatively design the system because its difficulty comes from a complicated mechanism of packet losses by congestion.

We introduced a sliding window mechanism to guarantee for reliable data delivery. The mechanism has a reliable data delivery as well as a data flow control between a sender and a receiver. In the mechanism, data transfer is controlled by an acknowledgement that is used for confirming of data transferred, and a sender transmits multiple packets before waiting for an acknowledgement, so the data are transferred in high efficiency.

We implemented the protocol and constructed systems to measure its performance. Since the protocol has a light workload, we implemented the protocol on a small hardware device to demonstrate that. We constructed various systems with the implementation on Ethernet. Since the protocol requires only packet switching function, we were able to use Ethernet hub and facilely constructed those system.

We employ a polling model in queuing theory for a mathematical model of the protocol. But since the model is mathematically simplified, we modified the equations of the model for our systems.

We measured the systems and analyzed these results with the mathematical model. We found that senders fairly transfer data among senders and the total bandwidth is above 90% from the measured results of transfer data rate variations. Since the calculated average message lengths were good agreement with measured results, we can predict it with given an average transfer data rate of senders and an average message waiting-times can be calculated.

We also measured and analyzed various systems which have different number of senders and network topologies. From the results, we found that these system performances can be calculated and we can quantitatively design a large scale network system. And we found that the protocol was more suitable for DAQ systems than TCP with comparison them.

From these results, the protocol is suitable for the DAQ systems and we can conclude that we can quantitatively design and construct a high performance DAQ system with the new protocol.

論文の審査結果の要旨

出願者内田智久君の発表及びそれに関連する質疑応答を２時間半にわたって行い、さらに出願者退席の後審査を行った。

内田智久君の博士論文は、大規模実験のデータ収集の効率化を実現するために、既存のネットワーク規格を基に新しい技術を考案し、その実装と試験を行って有用性を確認したものである。待ち行列理論を用いて理論的予測値と実測データの比較も行っており、大規模実験用データ収集システムの設計のために非常に有意義な研究である。

論文は以下の構成となっている。まず、大規模実験のデータ収集システムを概観して、ネットワーク技術を利用することの重要性を指摘したうえで、通常利用されるネットワークと実験データ収集で必要とされるネットワークの利用方法が非常に違っていることから、データ収集用に特化した通信プロトコルの導入の必要性を説明している。続いて、データ収集の特徴と既存の規格の整合性を考慮した新しい通信プロトコル(Data Collection Protocol = DCP)を概説し、その実装の詳細を論じている。続いて、待ち行列理論を用いてデータ収集システムをモデル化し、システム設計に際して重要となるパラメータの間の関係式を導出し、さらに、いくつかの異なったネットワーク構成について理論的予測値と実測データを比較してモデルの正当性・有効性を確認している。また、汎用通信プロトコル(TCP)と DCP の比較を行い、データ収集における DCP の優位性を説いている。その後、新プロトコル(DCP)を利用した様々な可能性について論じている。

高エネルギー素粒子原子核実験においては、実験規模の拡大や精密化に伴いデータ収集システムにネットワークを利用することが一般的に行われている。しかしながら、データ収集におけるデータの流れは同時に一方向に集中する傾向を持っており汎用ネットワークを効率良く利用するには様々な技法が必要とされてきた。

内田智久君は、高エネルギー素粒子原子核実験におけるデータの流れを深く考察し、その特徴を利用することで、簡単なプロトコルで効率良くデータを転送する手法を見出した。更に、そのプロトコルが単純であることから、待ち行列理論を用いてデータ収集システムの主要パラメータが容易に計算できること、データの流れに対し複雑な制御を用いなくても動的に高効率なデータ転送が行えることを示した。

これまでにもデータの流れを制御する方法はいくつか考案され実装されているが、トークンをネットワーク上で論理的に実装することによりハードウェアを新たに設計製作する必要がないというこれまでに行われていなかった画期的な

発想に基づいている。

以上述べたように、本論文に示された新しいプロトコル及び待ち行列理論に基づくモデルは、今後の大規模データ収集システムの設計の際に多大な寄与が期待される。本論文は素粒子原子核専攻の博士学位論文として高い水準になり、またその研究は本専攻に相応しい内容を持つものであると判定した。