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Introduction to Accounting Management

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Abstract

The field of Accounting Management is concerned with the collection of resource consumption data for the purposes of capacity and trend analysis, cost allocation, auditing, and billing. This document describes each of these problems, and discusses the issues involved in design of modern accounting systems.

Since accounting applications do not have uniform security and reliability requirements, it is not possible to devise a single accounting protocol and set of security services that will meet all needs. Thus the goal of accounting management is to provide a set of tools that can be used to meet the requirements of each application. This document describes the currently available tools as well as the state of the art in accounting protocol design. A companion document, RFC 2924, reviews the state of the art in accounting attributes and record formats.

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1. Introduction

The field of Accounting Management is concerned with the collection of resource consumption data for the purposes of capacity and trend analysis, cost allocation, auditing, and billing. This document describes each of these problems, and discusses the issues involved in design of modern accounting systems.

Since accounting applications do not have uniform security and reliability requirements, it is not possible to devise a single accounting protocol and set of security services that will meet all needs. Thus the goal of accounting management is to provide a set of tools that can be used to meet the requirements of each application. This document describes the currently available tools as well as the state of the art in accounting protocol design. A companion document, RFC 2924, reviews the state of the art in accounting attributes and record formats.

1.1. Requirements language

In this document, the key words "MAY", "MUST, "MUST NOT", "optional", "recommended", "SHOULD", and "SHOULD NOT", are to be interpreted as described in [6].

1.2. Terminology

This document frequently uses the following terms:

Accounting
: The collection of resource consumption data for the purposes of capacity and trend analysis, cost allocation, auditing, and billing. Accounting management requires that resource consumption be measured, rated, assigned, and communicated between appropriate parties.

Archival accounting
: In archival accounting, the goal is to collect all accounting data, to reconstruct missing entries as best as possible in the event of data loss, and to archive data for a mandated time period. It is "usual and customary" for these systems to be engineered to be very robust against accounting data loss. This may include provisions for transport layer as well as application layer acknowledgments, use of non-volatile storage, interim accounting capabilities (stored or transmitted over the wire), etc. Legal or financial requirements frequently mandate archival accounting practices, and may often dictate that data be kept confidential, regardless of whether it is to be used for billing purposes or not.

Rating
: The act of determining the price to be charged for use of a resource.

Billing
: The act of preparing an invoice.

Usage sensitive billing
: A billing process that depends on usage information to prepare an invoice can be said to be usage-sensitive. In contrast, a process that is independent of usage information is said to be non-usage-sensitive.

Auditing
: The act of verifying the correctness of a procedure. In order to be able to conduct an audit it is necessary to be able to definitively determine what procedures were actually carried out so as to be able to compare this to

the recommended process. Accomplishing this may require security services such as authentication and integrity protection.

Cost Allocation
: The act of allocating costs between entities. Note that cost allocation and rating are fundamentally different processes. In cost allocation the objective is typically to allocate a known cost among several entities. In rating the objective is to determine the amount to be charged for use of a resource. In cost allocation, the cost per unit of resource may need to be determined; in rating, this is typically a given.

Interim accounting
: Interim accounting provides a snapshot of usage during a user's session. This may be useful in the event of a device reboot or other network problem that prevents the reception or generation of a session summary packet or session record. Interim accounting records can always be summarized without the loss of information. Note that interim accounting records may be stored internally on the device (such as in non-volatile storage) so as to survive a reboot and thus may not always be transmitted over the wire.

Session record
: A session record represents a summary of the resource consumption of a user over the entire session. Accounting gateways creating the session record may do so by processing interim accounting events or accounting events from several devices serving the same user.

Accounting Protocol
: A protocol used to convey data for accounting purposes.

Intra-domain accounting
: Intra-domain accounting involves the collection of information on resource usage within an administrative domain, for use within that domain. In intra-domain accounting, accounting packets and session records typically do not cross administrative boundaries.

Inter-domain accounting
: Inter-domain accounting involves the collection of information on resource usage within an administrative

domain, for use within another administrative domain. In inter-domain accounting, accounting packets and session records will typically cross administrative boundaries.

Real-time accounting
: Real-time accounting involves the processing of information on resource usage within a defined time window. Time constraints are typically imposed in order to limit financial risk.

Accounting server
: The accounting server receives accounting data from devices and translates it into session records. The accounting server may also take responsibility for the routing of session records to interested parties.

1.3. Accounting management architecture

The accounting management architecture involves interactions between network devices, accounting servers, and billing servers. The network device collects resource consumption data in the form of accounting metrics. This information is then transferred to an accounting server. Typically this is accomplished via an accounting protocol, although it is also possible for devices to generate their own session records.

The accounting server then processes the accounting data received from the network device. This processing may include summarization of interim accounting information, elimination of duplicate data, or generation of session records.

The processed accounting data is then submitted to a billing server, which typically handles rating and invoice generation, but may also carry out auditing, cost allocation, trend analysis or capacity planning functions. Session records may be batched and compressed by the accounting server prior to submission to the billing server in order to reduce the volume of accounting data and the bandwidth required to accomplish the transfer.

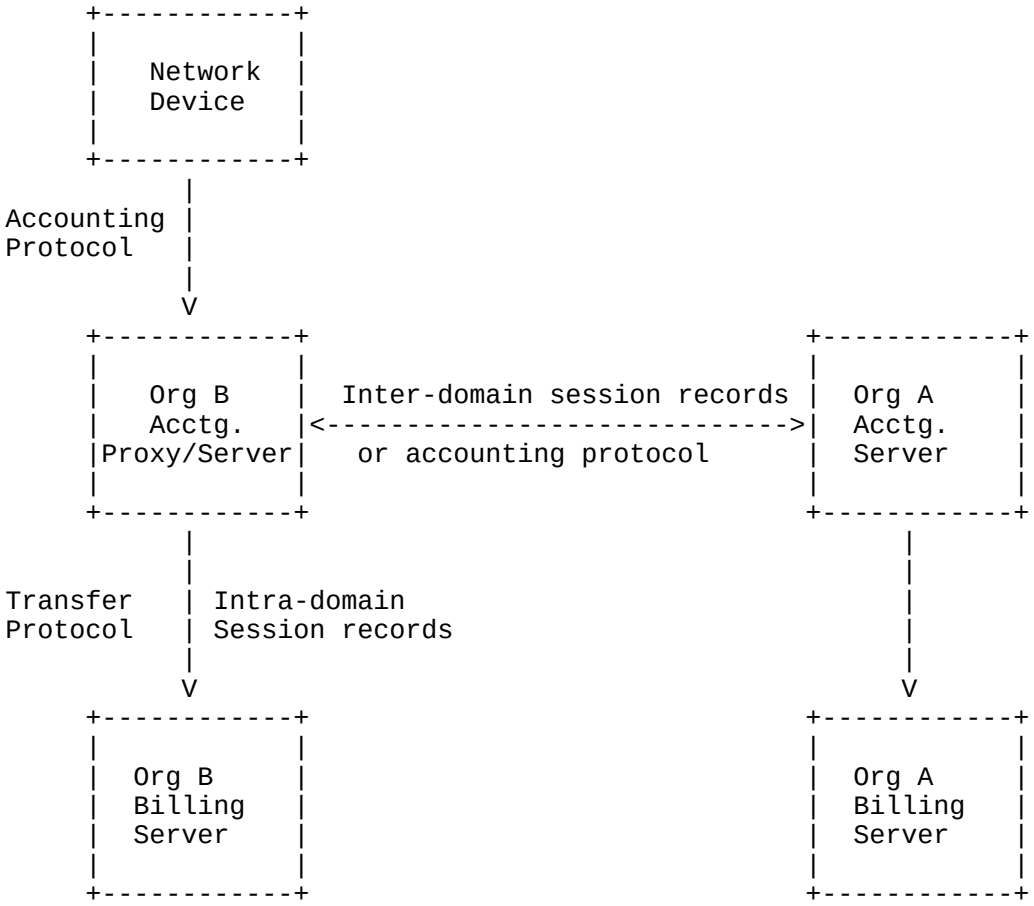
One of the functions of the accounting server is to distinguish between inter and intra-domain accounting events and to route them appropriately. For session records containing a Network Access Identifier (NAI), described in [8], the distinction can be made by examining the domain portion of the NAI. If the domain portion is absent or corresponds to the local domain, then the session record is treated as an intra-domain accounting event. Otherwise, it is treated as an inter-domain accounting event.

Intra-domain accounting events are typically routed to the local billing server, while inter-domain accounting events will be routed to accounting servers operating within other administrative domains. While it is not required that session record formats used in inter and intra-domain accounting be the same, this is desirable, since it eliminates translations that would otherwise be required.

Where a proxy forwarder is employed, domain-based access controls may be employed by the proxy forwarder, rather than by the devices themselves. The network device will typically speak an accounting protocol to the proxy forwarder, which may then either convert the accounting packets to session records, or forward the accounting packets to another domain. In either case, domain separation is typically achieved by having the proxy forwarder sort the session records or accounting messages by destination.

Where the accounting proxy is not trusted, it may be difficult to verify that the proxy is issuing correct session records based on the accounting messages it receives, since the original accounting messages typically are not forwarded along with the session records. Therefore where trust is an issue, the proxy typically forwards the accounting packets themselves. Assuming that the accounting protocol supports data object security, this allows the end-points to verify that the proxy has not modified the data in transit or snooped on the packet contents.

The diagram below illustrates the accounting management architecture:



1.4. Accounting management objectives

Accounting Management involves the collection of resource consumption data for the purposes of capacity and trend analysis, cost allocation, auditing, billing. Each of these tasks has different requirements.

1.4.1. Trend analysis and capacity planning

In trend analysis and capacity planning, the goal is typically a forecast of future usage. Since such forecasts are inherently imperfect, high reliability is typically not required, and moderate packet loss can be tolerated. Where it is possible to use statistical sampling techniques to reduce data collection

requirements while still providing the forecast with the desired statistical accuracy, it may be possible to tolerate high packet loss as long as bias is not introduced.

The security requirements for trend analysis and capacity planning depend on the circumstances of data collection and the sensitivity of the data. Additional security services may be required when data is being transferred between administrative domains. For example, when information is being collected and analyzed within the same administrative domain, integrity protection and authentication may be used in order to guard against collection of invalid data. In inter-domain applications confidentiality may be desirable to guard against snooping by third parties.

1.4.2. Billing

When accounting data is used for billing purposes, the requirements depend on whether the billing process is usage-sensitive or not.

1.4.2.1. Non-usage sensitive billing

Since by definition, non-usage-sensitive billing does not require usage information, in theory all accounting data can be lost without affecting the billing process. Of course this would also affect other tasks such as trend analysis or auditing, so that such wholesale data loss would still be unacceptable.

1.4.2.2. Usage-sensitive billing

Since usage-sensitive billing processes depend on usage information, packet loss may translate directly to revenue loss. As a result, the billing process may need to conform to financial reporting and legal requirements, and therefore an archival accounting approach may be needed.

Usage-sensitive systems may also require low processing delay. Today credit risk is commonly managed by computerized fraud detection systems that are designed to detect unusual activity. While efficiency concerns might otherwise dictate batched transmission of accounting data, where there is a risk of fraud, financial exposure increases with processing delay. Thus it may be advisable to transmit each event individually to minimize batch size, or even to utilize quality of service techniques to minimize queuing delays. In addition, it may be necessary for authorization to be dependent on ability to pay.

Whether these techniques will be useful varies by application since the degree of financial exposure is application-dependent. For dial-up Internet access from a local provider, charges are typically low and therefore the risk of loss is small. However, in the case of dial-up roaming or voice over IP, time-based charges may be substantial and therefore the risk of fraud is larger. In such situations it is highly desirable to quickly detect unusual account activity, and it may be desirable for authorization to depend on ability to pay. In situations where valuable resources can be reserved, or where charges can be high, very large bills may be rung up quickly, and processing may need to be completed within a defined time window in order to limit exposure.

Since in usage-sensitive systems, accounting data translates into revenue, the security and reliability requirements are greater. Due to financial and legal requirements such systems need to be able to survive an audit. Thus security services such as authentication, integrity and replay protection are frequently required and confidentiality and data object integrity may also be desirable. Application-layer acknowledgments are also often required so as to guard against accounting server failures.

1.4.3. Auditing

With enterprise networking expenditures on the rise, interest in auditing is increasing. Auditing, which is the act of verifying the correctness of a procedure, commonly relies on accounting data. Auditing tasks include verifying the correctness of an invoice submitted by a service provider, or verifying conformance to usage policy, service level agreements, or security guidelines.

To permit a credible audit, the auditing data collection process must be at least as reliable as the accounting process being used by the entity that is being audited. Similarly, security policies for the audit should be at least as stringent as those used in preparation of the original invoice. Due to financial and legal requirements, archival accounting practices are frequently required in this application.

Where auditing procedures are used to verify conformance to usage or security policies, security services may be desired. This typically will include authentication, integrity and replay protection as well as confidentiality and data object integrity. In order to permit response to security incidents in progress, auditing applications frequently are built to operate with low processing delay.

1.4.4. Cost allocation

The application of cost allocation and billback methods by enterprise customers is not yet widespread. However, with the convergence of telephony and data communications, there is increasing interest in applying cost allocation and billback procedures to networking costs, as is now commonly practiced with telecommunications costs.

Cost allocation models, including traditional costing mechanisms described in [21]-[23] and activity-based costing techniques described in [24] are typically based on detailed analysis of usage data, and as a result they are almost always usage-sensitive. Whether these techniques are applied to allocation of costs between partners in a venture or to allocation of costs between departments in a single firm, cost allocation models often have profound behavioral and financial impacts. As a result, systems developed for this purposes are typically as concerned with reliable data collection and security as are billing applications. Due to financial and legal requirements, archival accounting practices are frequently required in this application.

1.5. Intra-domain and inter-domain accounting

Much of the initial work on accounting management has focused on intra-domain accounting applications. However, with the increasing deployment of services such as dial-up roaming, Internet fax, Voice and Video over IP and QoS, applications requiring inter-domain accounting are becoming increasingly common.

Inter-domain accounting differs from intra-domain accounting in several important ways. Intra-domain accounting involves the collection of information on resource consumption within an administrative domain, for use within that domain. In intra-domain accounting, accounting packets and session records typically do not cross administrative boundaries. As a result, intra-domain accounting applications typically experience low packet loss and involve transfer of data between trusted entities.

In contrast, inter-domain accounting involves the collection of information on resource consumption within an administrative domain, for use within another administrative domain. In inter-domain accounting, accounting packets and session records will typically cross administrative boundaries. As a result, inter-domain accounting applications may experience substantial packet loss. In addition, the entities involved in the transfers cannot be assumed to trust each other.

Since inter-domain accounting applications involve transfers of accounting data between domains, additional security measures may be desirable. In addition to authentication, replay and integrity protection, it may be desirable to deploy security services such as confidentiality and data object integrity. In inter-domain accounting each involved party also typically requires a copy of each accounting event for invoice generation and auditing.

1.6. Accounting record production

Typically, a single accounting record is produced per session, or in some cases, a set of interim records which can be summarized in a single record for billing purposes. However, to support deployment of services such as wireless access or complex billing regimes, a more sophisticated approach is required.

It is necessary to generate several accounting records from a single session when pricing changes during a session. For instance, the price of a service can be higher during peak hours than off-peak. For a session continuing from one tariff period to another, it becomes necessary for a device to report "packets sent" during both periods.

Time is not the only factor requiring this approach. For instance, in mobile access networks the user may roam from one place to another while still being connected in the same session. If roaming causes a change in the tariffs, it is necessary to account for resource consumed in the first and second areas. Another example is where modifications are allowed to an ongoing session. For example, it is possible that a session could be re-authorized with improved QoS. This would require production of accounting records at both QoS levels.

These examples could be addressed by using vectors or multi-dimensional arrays to represent resource consumption within a single session record. For example, the vector or array could describe the resource consumption for each combination of factors, e.g. one data item could be the number of packets during peak hour in the area of the home operator. However, such an approach seems complicated and inflexible and as a result, most current systems produce a set of records from one session. A session identifier needs to be present in the records to permit accounting systems to tie the records together.

In most cases, the network device will determine when multiple session records are needed, as the local device is aware of factors affecting local tariffs, such as QoS changes and roaming. However, future systems are being designed that enable the home domain to

control the generation of accounting records. This is of importance in inter-domain accounting or when network devices do not have tariff information. The centralized control of accounting record production can be realized, for instance, by having authorization servers require re-authorization at certain times and requiring the production of accounting records upon each re-authorization.

In conclusion, in some cases it is necessary to produce multiple accounting records from a single session. It must be possible to do this without requiring the user to start a new session or to re-authenticate. The production of multiple records can be controlled either by the network device or by the AAA server. The requirements for timeliness, security and reliability in multiple record sessions are the same as for single-record sessions.

1.7. Requirements summary

Usage	Intra-domain	Inter-domain
Capacity Planning	Robustness vs. packet loss Integrity, authentication, replay protection [confidentiality]	Robustness vs. packet loss Integrity, authentication, replay prot. confidentiality [data object sec.]
Non-usage Sensitive Billing	Integrity, authentication, replay protection [confidentiality]	Integrity, authentication, replay protection confidentiality [data object sec.]
Usage Sensitive Billing, Cost Allocation & Auditing	Archival accounting Integrity, authentication, replay protection [confidentiality] [Bounds on processing delay]	Archival accounting Integrity, authentication, replay prot. confidentiality [data object sec.] [Bounds on processing delay]
Time Sensitive Billing, fraud detection, roaming	Archival accounting Integrity, authentication, replay protection [confidentiality] Bounds on processing delay	Archival accounting Integrity, authentication, replay prot. confidentiality [Data object security and receipt support] Bounds on processing delay

Key
[] = optional

2. Scaling and reliability

With the continuing growth of the Internet, it is important that accounting management systems be scalable and reliable. This section discusses the resources consumed by accounting management systems as well as the scalability and reliability properties exhibited by various data collection and transport models.

2.1. Fault resilience

As noted earlier, in applications such as usage-sensitive billing, cost allocation and auditing, an archival approach to accounting is frequently mandated, due to financial and legal requirements. Since in such situations loss of accounting data can translate to revenue loss, there is incentive to engineer a high degree of fault resilience. Faults which may be encountered include:

Packet loss
Accounting server failures
Network failures
Device reboots

To date, much of the debate on accounting reliability has focused on resilience against packet loss and the differences between UDP, SCTP and TCP-based transport. However, it should be understood that resilience against packet loss is only one aspect of meeting archival accounting requirements.

As noted in [18], "once the cable is cut you don’t need more retransmissions, you need a *lot* more voltage." Thus, the choice of transport has no impact on resilience against faults such as network partition, accounting server failures or device reboots. What does provide resilience against these faults is non-volatile storage.

The importance of non-volatile storage in design of reliable accounting systems cannot be over-emphasized. Without non-volatile storage, event-driven systems will lose data once the transmission timeout has been exceeded, and batching designs will experience data loss once the internal memory used for accounting data storage has been exceeded. Via use of non-volatile storage, and internally stored interim records, most of these data losses can be avoided.

It may even be argued that non-volatile storage is more important to accounting reliability than network connectivity, since for many years reliable accounting systems were implemented based solely on physical storage, without any network connectivity. For example,

phone usage data used to be stored on paper, film, or magnetic media and carried from the place of collection to a central location for bill processing.

2.1.1. Interim accounting

Interim accounting provides protection against loss of session summary data by providing checkpoint information that can be used to reconstruct the session record in the event that the session summary information is lost. This technique may be applied to any data collection model (i.e. event-driven or polling) and is supported in both RADIUS [25] and in TACACS+.

While interim accounting can provide resilience against packet loss, server failures, short-duration network failures, or device reboot, its applicability is limited. Transmission of interim accounting data over the wire should not be thought of as a mainstream reliability improvement technique since it increases use of network bandwidth in normal operation, while providing benefits only in the event of a fault.

Since most packet loss on the Internet is due to congestion, sending interim accounting data over the wire can make the problem worse by increasing bandwidth usage. Therefore on-the-wire interim accounting is best restricted to high-value accounting data such as information on long-lived sessions. To protect against loss of data on such sessions, the interim reporting interval is typically set several standard deviations larger than the average session duration. This ensures that most sessions will not result in generation of interim accounting events and the additional bandwidth consumed by interim accounting will be limited. However, as the interim accounting interval decreases toward the average session time, the additional bandwidth consumed by interim accounting increases markedly, and as a result, the interval must be set with caution.

Where non-volatile storage is unavailable, interim accounting can also result in excessive consumption of memory that could be better allocated to storage of session data. As a result, implementors should be careful to ensure that new interim accounting data overwrites previous data rather than accumulating additional interim records in memory, thereby worsening the buffer exhaustion problem.

Given the increasing popularity of non-volatile storage for use in consumer devices such as digital cameras, such devices are rapidly declining in price. This makes it increasingly feasible for network devices to include built-in support for non-volatile storage. This can be accomplished, for example, by support for compact PCMCIA cards.

Where non-volatile storage is available, this can be used to store interim accounting data. Stored interim events are then replaced by updated interim events or by session data when the session completes. The session data can itself be erased once the data has been transmitted and acknowledged at the application layer. This approach avoids interim data being transmitted over the wire except in the case of a device reboot. When a device reboots, internally stored interim records are transferred to the accounting server.

2.1.2. Multiple record sessions

Generation of multiple accounting records within a session can introduce scalability problems that cannot be controlled using the techniques available in interim accounting.

For example, in the case of interim records kept in non-volatile storage, it is possible to overwrite previous interim records with the most recent one or summarize them to a session record. Where interim updates are sent over the wire, it is possible to control bandwidth usage by adjusting the interim accounting interval.

These measures are not applicable where multiple session records are produced from a single session, since these records cannot be summarized or overwritten without loss of information. As a result, multiple record production can result in increased consumption of bandwidth and memory. Implementors should be careful to ensure that worst-case multiple record processing requirements do not exceed the capabilities of their systems.

As an example, a tariff change at a particular time of day could, if implemented carelessly, create a sudden peak in the consumption of memory and bandwidth as the records need to be stored and/or transported. Rather than attempting to send all of the records at once, it may be desirable to keep them in non-volatile storage and send all of the related records together in a batch when the session completes. It may also be desirable to shape the accounting traffic flow so as to reduce the peak bandwidth consumption. This can be accomplished by introduction of a randomized delay interval. If the home domain can also control the generation of multiple accounting records, the estimation of the worst-case processing requirements can be very difficult.

2.1.3. Packet loss

As packet loss is a fact of life on the Internet, accounting protocols dealing with session data need to be resilient against packet loss. This is particularly important in inter-domain accounting, where packets often pass through Network Access Points

(NAPs) where packet loss may be substantial. Resilience against packet loss can be accomplished via implementation of a retry mechanism on top of UDP, or use of TCP [7] or SCTP [26]. On-the-wire interim accounting provides only limited benefits in mitigating the effects of packet loss.

UDP-based transport is frequently used in accounting applications. However, this is not appropriate in all cases. Where accounting data will not fit within a single UDP packet without fragmentation, use of TCP or SCTP transport may be preferred to use of multiple round-trips in UDP. As noted in [47] and [49], this may be an issue in the retrieval of large tables.

In addition, in cases where congestion is likely, such as in inter-domain accounting, TCP or SCTP congestion control and round-trip time estimation will be very useful, optimizing throughput. In applications which require maintenance of session state, such as simultaneous usage control, TCP and application-layer keep alive packets or SCTP with its built-in heartbeat capabilities provide a mechanism for keeping track of session state.

When implementing UDP retransmission, there are a number of issues to keep in mind:

- Data model
- Retry behavior
- Congestion control
- Timeout behavior

Accounting reliability can be influenced by how the data is modeled. For example, it is almost always preferable to use cumulative variables rather than expressing accounting data in terms of a change from a previous data item. With cumulative data, the current state can be recovered by a successful retrieval, even after many packets have been lost. However, if the data is transmitted as a change then the state will not be recovered until the next cumulative update is sent. Thus, such implementations are much more vulnerable to packet loss, and should be avoided wherever possible.

In designing a UDP retry mechanism, it is important that the retry timers relate to the round-trip time, so that retransmissions will not typically occur within the period in which acknowledgments may be expected to arrive. Accounting bandwidth may be significant in some circumstances, so that the added traffic due to unnecessary retransmissions may increase congestion levels.

Congestion control in accounting data transfer is a somewhat controversial issue. Since accounting traffic is often considered mission-critical, it has been argued that congestion control is not a requirement; better to let other less-critical traffic back off in response to congestion. Moreover, without non-volatile storage, congestive back-off in accounting applications can result in data loss due to buffer exhaustion.

However, it can also be argued that in modern accounting implementations, it is possible to implement congestion control while improving throughput and maintaining high reliability. In circumstances where there is sustained packet loss, there simply is not sufficient capacity to maintain existing transmission rates. Thus, aggregate throughput will actually improve if congestive back-off is implemented. This is due to elimination of retransmissions and the ability to utilize techniques such as RED to desynchronize flows. In addition, with QoS mechanisms such as differentiated services, it is possible to mark accounting packets for preferential handling so as to provide for lower packet loss if desired. Thus considerable leeway is available to the network administrator in controlling the treatment of accounting packets and hard coding inelastic behavior is unnecessary. Typically, systems implementing non-volatile storage allow for backlogged accounting data to be placed in non-volatile storage pending transmission, so that buffer exhaustion resulting from congestive back-off need not be a concern.

Since UDP is not really a transport protocol, UDP-based accounting protocols such as [4] often do not prescribe timeout behavior. Thus implementations may exhibit widely different behavior. For example, one implementation may drop accounting data after three constant duration retries to the same server, while another may implement exponential back-off to a given server, then switch to another server, up to a total timeout interval of twelve hours, while storing the untransmitted data on non-volatile storage. The practical difference between these approaches is substantial; the former approach will not satisfy archival accounting requirements while the latter may. More predictable behavior can be achieved via use of SCTP or TCP transport.

2.1.4. Accounting server failover

In the event of a failure of the primary accounting server, it is desirable for the device to failover to a secondary server. Providing one or more secondary servers can remove much of the risk of accounting server failure, and as a result use of secondary servers has become commonplace.

For protocols based on TCP, it is possible for the device to maintain connections to both the primary and secondary accounting servers, using the secondary connection after expiration of a timer on the primary connection. Alternatively, it is possible to open a connection to the secondary accounting server after a timeout or loss of the primary connection, or on expiration of a timer. Thus, accounting protocols based on TCP are capable of responding more rapidly to connectivity failures than TCP timeouts would otherwise allow, at the expense of an increased risk of duplicates.

With SCTP, it is possible to control transport layer timeout behavior, and therefore it is not necessary for the accounting application to maintain its own timers. SCTP also enables multiplexing of multiple connections within a single transport connection, all maintaining the same congestion control state, avoiding the "head of line blocking" issues that can occur with TCP. However, since SCTP is not widely available, use of this transport can impose an additional implementation burden on the designer.

For protocols using UDP, transmission to the secondary server can occur after a number of retries or timer expiration. For compatibility with congestion avoidance, it is advisable to incorporate techniques such as round-trip-time estimation, slow start and congestive back-off. Thus the accounting protocol designer utilizing UDP often is lead to re-inventing techniques already existing in TCP and SCTP. As a result, the use of raw UDP transport in accounting applications is not recommended.

With any transport it is possible for the primary and secondary accounting servers to receive duplicate packets, so support for duplicate elimination is required. Since accounting server failures can result in data accumulation on accounting clients, use of non-volatile storage can ensure against data loss due to transmission timeouts or buffer exhaustion. On-the-wire interim accounting provides only limited benefits in mitigating the effects of accounting server failures.

2.1.5. Application layer acknowledgments

It is possible for the accounting server to experience partial failures. For example, a failure in the database back end could leave the accounting retrieval process or thread operable while the process or thread responsible for storing the data is non-functional. Similarly, it is possible for the accounting application to run out of disk space, making it unable to continue storing incoming session records.

In such cases it is desirable to distinguish between transport layer acknowledgment and application layer acknowledgment. Even though both acknowledgments may be sent within the same packet (such as a TCP segment carrying an application layer acknowledgment along with a piggy-backed ACK), the semantics are different. A transport-layer acknowledgment means "the transport layer has taken responsibility for delivering the data to the application", while an application-layer acknowledgment means "the application has taken responsibility for the data".

A common misconception is that use of TCP transport guarantees that data is delivered to the application. However, as noted in RFC 793 [7]:

> An acknowledgment by TCP does not guarantee that the data has been delivered to the end user, but only that the receiving TCP has taken the responsibility to do so.

Therefore, if receiving TCP fails after sending the ACK, the application may not receive the data. Similarly, if the application fails prior to committing the data to stable storage, the data may be lost. In order for a sending application to be sure that the data it sent was received by the receiving application, either a graceful close of the TCP connection or an application-layer acknowledgment is required. In order to protect against data loss, it is necessary that the application-layer acknowledgment imply that the data has been written to stable storage or suitably processed so as to guard against loss.

In the case of partial failures, it is possible for the transport layer to acknowledge receipt via transport layer acknowledgment, without having delivered the data to the application. Similarly, the application may not complete the tasks necessary to take responsibility for the data.

For example, an accounting server may receive data from the transport layer but be incapable of storing it data due to a back end database problem or disk fault. In this case it should not send an application layer acknowledgment, even though a a transport layer acknowledgment is appropriate. Rather, an application layer error message should be sent indicating the source of the problem, such as "Backend store unavailable".

Thus application-layer acknowledgment capability requires not only the ability to acknowledge when the application has taken responsibility for the data, but also the ability to indicate when the application has not taken responsibility for the data, and why.

2.1.6. Network failures

Network failures may result in partial or complete loss of connectivity for the accounting client. In the event of partial connectivity loss, it may not be possible to reach the primary accounting server, in which case switch over to the secondary accounting server is necessary. In the event of a network partition, it may be necessary to store accounting events in device memory or non-volatile storage until connectivity can be re-established.

As with accounting server failures, on-the-wire interim accounting provides only limited benefits in mitigating the effects of network failures.

2.1.7. Device reboots

In the event of a device reboot, it is desirable to minimize the loss of data on sessions in progress. Such losses may be significant even if the devices themselves are very reliable, due to long-lived sessions, which can comprise a significant fraction of total resource consumption. To guard against loss of these high-value sessions, interim accounting data is typically transmitted over the wire. When interim accounting in-place is combined with non-volatile storage it becomes possible to guard against data loss in much shorter sessions. This is possible since interim accounting data need only be stored in non-volatile memory until the session completes, at which time the interim data may be replaced by the session record. As a result, interim accounting data need never be sent over the wire, and it is possible to decrease the interim interval so as to provide a very high degree of protection against data loss.

2.1.8. Accounting proxies

In order to maintain high reliability, it is important that accounting proxies pass through transport and application layer acknowledgments and do not store and forward accounting packets. This enables the end-systems to control re-transmission behavior and utilize techniques such as non-volatile storage and secondary servers to improve resilience.

Accounting proxies sending a transport or application layer ACK to the device without receiving one from the accounting server fool the device into thinking that the accounting request had been accepted by the accounting server when this is not the case. As a result, the device can delete the accounting packet from non-volatile storage before it has been accepted by the accounting server. The leaves the

accounting proxy responsible for delivering accounting packets. If the accounting proxy involves moving parts (e.g. a disk drive) while the devices do not, overall system reliability can be reduced.

Store and forward accounting proxies only add value in situations where the accounting subsystem is unreliable. For example, where devices do not implement non-volatile storage and the accounting protocol lacks transport and application layer reliability, locating the accounting proxy (with its stable storage) close to the device can reduce the risk of data loss.

However, such systems are inherently unreliable so that they are only appropriate for use in capacity planning or non-usage sensitive billing applications. If archival accounting reliability is desired, it is necessary to engineer a reliable accounting system from the start using the techniques described in this document, rather than attempting to patch an inherently unreliable system by adding store and forward accounting proxies.

2.1.9. Fault resilience summary

Fault	Counter-measures
Packet loss	Retransmission based on RTT
	Congestion control
	Well-defined timeout behavior
	Duplicate elimination
	Interim accounting*
	Non-volatile storage
	Cumulative variables
Accounting server & net failures	Primary-secondary servers
	Duplicate elimination
	Interim accounting*
	Application layer ACK & error msgs.
	Non-volatile storage
Device reboots	Interim accounting*
	Non-volatile storage

Key
* = limited usefulness without non-volatile storage

Note: Accounting proxies are not a reliability enhancement mechanism.

2.2. Resource consumption

In the process of growing to meet the needs of providers and customers, accounting management systems consume a variety of resources, including:

- Network bandwidth
- Memory
- Non-volatile storage
- State on the accounting management system
- CPU on the management system and managed devices

In order to understand the limits to scaling, we examine each of these resources in turn.

2.2.1. Network bandwidth

Accounting management systems consume network bandwidth in transferring accounting data. The network bandwidth consumed is proportional to the amount of data transferred, as well as required network overhead. Since accounting data for a given event may be 100 octets or less, if each event is transferred individually, overhead can represent a considerable proportion of total bandwidth consumption. As a result, it is often desirable to transfer accounting data in batches, enabling network overhead to be spread over a larger payload, and enabling efficient use of compression. As noted in [48], compression can be enabled in the accounting protocol, or can be done at the IP layer as described in [5].

2.2.2. Memory

In accounting systems without non-volatile storage, accounting data must be stored in volatile memory during the period between when it is generated and when it is transferred. The resulting memory consumption will depend on retry and retransmission algorithms. Since systems designed for high reliability will typically wish to retry for long periods, or may store interim accounting data, the resulting memory consumption can be considerable. As a result, if non-volatile storage is unavailable, it may be desirable to compress accounting data awaiting transmission.

As noted earlier, implementors of interim accounting should take care to ensure against excessive memory usage by overwriting older interim accounting data with newer data for the same session rather than accumulating interim data in the buffer.

2.2.3. Non-volatile storage

Since accounting data stored in memory will typically be lost in the event of a device reboot or a timeout, it may be desirable to provide non-volatile storage for undelivered accounting data. With the costs of non-volatile storage declining rapidly, network devices will be increasingly capable of incorporating non-volatile storage support over the next few years.

Non-volatile storage may be used to store interim or session records. As with memory utilization, interim accounting overwrite is desirable so as to prevent excessive storage consumption. Note that the use of ASCII data representation enables use of highly efficient text compression algorithms that can minimize storage requirements. Such

compression algorithms are only typically applied to session records so as to enable implementation of interim data overwrite.

2.2.4. State on the accounting management system

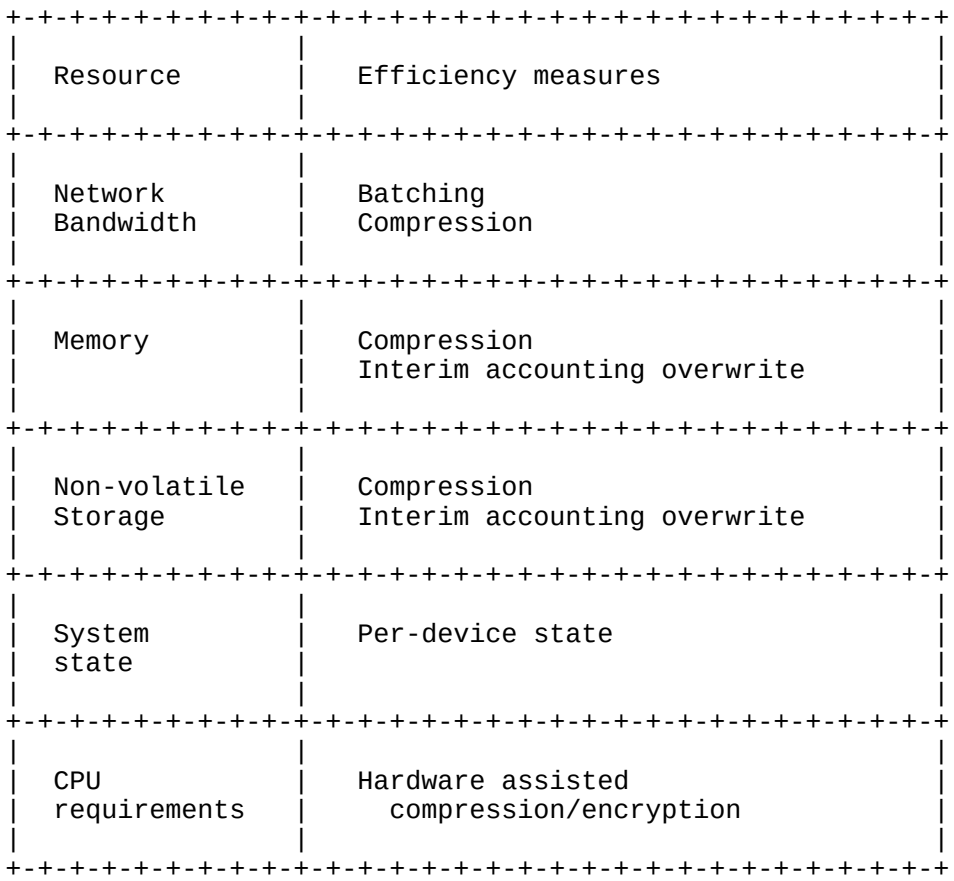
In order to keep track of received accounting data, accounting management systems may need to keep state on managed devices or concurrent sessions. Since the number of devices is typically much smaller than the number of concurrent sessions, it is desirable to keep only per-device state if possible.

2.2.5. CPU requirements

CPU consumption of the managed and managing nodes will be proportional to the complexity of the required accounting processing. Operations such as ASN.1 encoding and decoding, compression/decompression, and encryption/decryption can consume considerable resources, both on accounting clients and servers.

The effect of these operations on accounting system reliability should not be under-estimated, particularly in the case of devices with moderate CPU resources. In the event that devices are over-taxed by accounting tasks, it is likely that overall device reliability will suffer.

2.2.6. Efficiency measures



2.3. Data collection models

Several data collection models are currently in use today for the purposes of accounting data collection. These include:

Polling model
Event-driven model without batching
Event-driven model with batching
Event-driven polling model

2.3.1. Polling model

In the polling model, an accounting manager will poll devices for accounting information at regular intervals. In order to ensure against loss of data, the polling interval will need to be shorter than the maximum time that accounting data can be stored on the polled device. For devices without non-volatile stage, this is typically determined by available memory; for devices with non-volatile storage the maximum polling interval is determined by the size of non-volatile storage.

The polling model results in an accumulation of data within individual devices, and as a result, data is typically transferred to the accounting manager in a batch, resulting in an efficient transfer process. In terms of Accounting Manager state, polling systems scale with the number of managed devices, and system bandwidth usage scales with the amount of data transferred.

Without non-volatile storage, the polling model results in loss of accounting data due to device reboots, but not due to packet loss or network failures of sufficiently short duration to be handled within available memory. This is because the Accounting Manager will continue to poll until the data is received. In situations where operational difficulties are encountered, the volume of accounting data will frequently increase so as to make data loss more likely. However, in this case the polling model will detect the problem since attempts to reach the managed devices will fail.

The polling model scales poorly for implementation of shared use or roaming services, including wireless data, Internet telephony, QoS provisioning or Internet access. This is because in order to retrieve accounting data for users within a given domain, the Accounting Management station would need to periodically poll all devices in all domains, most of which would not contain any relevant data. There are also issues with processing delay, since use of a polling interval also implies an average processing delay of half the polling interval. This may be too high for accounting data that requires low processing delay. Thus the event-driven polling or the pure event-driven approach is more appropriate for usage sensitive billing applications such as shared use or roaming implementations.

Per-device state is typical of polling-based network management systems, which often also carry out accounting management functions, since network management systems need to keep track of the state of network devices for operational purposes. These systems offer average processing delays equal to half the polling interval.

2.3.2. Event-driven model without batching

In the event-driven model, a device will contact the accounting server or manager when it is ready to transfer accounting data. Most event-driven accounting systems, such as those based on RADIUS accounting, described in [4], transfer only one accounting event per packet, which is inefficient.

Without non-volatile storage, a pure event-driven model typically stores accounting events that have not yet been delivered only until the timeout interval expires. As a result this model has the smallest memory requirements. Once the timeout interval has expired, the accounting event is lost, even if the device has sufficient buffer space to continue to store it. As a result, the event-driven model is the least reliable, since accounting data loss will occur due to device reboots, sustained packet loss, or network failures of duration greater than the timeout interval. In event-driven protocols without a "keep alive" message, accounting servers cannot assume a device failure should no messages arrive for an extended period. Thus, event-driven accounting systems are typically not useful in monitoring of device health.

The event-driven model is frequently used in shared use networks and roaming, since this model sends data to the recipient domains without requiring them to poll a large number of devices, most of which have no relevant data. Since the event-driven model typically does not support batching, it permits accounting records to be sent with low processing delay, enabling application of fraud prevention techniques. However, because roaming accounting events are frequently of high value, the poor reliability of this model is an issue. As a result, the event-driven polling model may be more appropriate.

Per-session state is typical of event-driven systems without batching. As a result, the event-driven approach scales poorly. However, event-driven systems offer the lowest processing delay since events are processed immediately and there is no possibility of an event requiring low processing delay being caught behind a batch transfer.

2.3.3. Event-driven model with batching

In the event-driven model with batching, a device will contact the accounting server or manager when it is ready to transfer accounting data. The device can contact the server when a batch of a given size has been gathered, when data of a certain type is available or after a minimum time period has elapsed. Such systems can transfer more than one accounting event per packet and are thus more efficient.

An event-driven system with batching will store accounting events that have not yet been delivered up to the limits of memory. As a result, accounting data loss will occur due to device reboots, but not due to packet loss or network failures of sufficiently short duration to be handled within available memory. Note that while transfer efficiency will increase with batch size, without non-volatile storage, the potential data loss from a device reboot will also increase.

Where event-driven systems with batching have a keep-alive interval and run over reliable transport, the accounting server can assume that a failure has occurred if no messages are received within the keep-alive interval. Thus, such implementations can be useful in monitoring of device health. When used for this purpose the average time delay prior to failure detection is one half the keep-alive interval.

Through implementation of a scheduling algorithm, event-driven systems with batching can deliver appropriate service to accounting events that require low processing delay. For example, high-value inter-domain accounting events could be sent immediately, thus enabling use of fraud-prevention techniques, while all other events would be batched. However, there is a possibility that an event requiring low processing delay will be caught behind a batch transfer in progress. Thus the maximum processing delay is proportional to the maximum batch size divided by the link speed.

Event-driven systems with batching scale with the number of active devices. As a result this approach scales better than the pure event-driven approach, or even the polling approach, and is equivalent in terms of scaling to the event-driven polling approach. However, the event-driven batching approach has lower processing delay than the event-driven polling approach, since delivery of accounting data requires fewer round-trips and events requiring low processing delay can be accommodated if a scheduling algorithm is employed.

2.3.4. Event-driven polling model

In the event-driven polling model an accounting manager will poll the device for accounting data only when it receives an event. The accounting client can generate an event when a batch of a given size has been gathered, when data of a certain type is available or after a minimum time period has elapsed. Note that while transfer efficiency will increase with batch size, without non-volatile storage, the potential data loss from a device reboot will also increase.

Without non-volatile storage, an event-driven polling model will lose data due to device reboots, but not due to packet loss, or network partitions of short-duration. Unless a minimum delivery interval is set, event-driven polling systems are not useful in monitoring of device health.

The event-driven polling model can be suitable for use in roaming since it permits accounting data to be sent to the roaming partners with low processing delay. At the same time non-roaming accounting can be handled via more efficient polling techniques, thereby providing the best of both worlds.

Where batching can be implemented, the state required in event-driven polling can be reduced to scale with the number of active devices. If portions of the network vary widely in usage, then this state may actually be less than that of the polling approach. Note that processing delay in this approach is higher than in event-driven accounting with batching since at least two round-trips are required to deliver data: one for the event notification, and one for the resulting poll.

2.3.5. Data collection summary

Model	Pros	Cons
Polling	Per-device state Robust against packet loss Batch transfers	Not robust against device reboot, server or network failures* Polling interval determined by storage limit High processing delay Unsuitable for use in roaming
Event-driven, no batching	Lowest processing delay Suitable for use in roaming	Not robust against packet loss, device reboot, or network failures* Low efficiency Per-session state
Event-driven, with batching and scheduling	Single round-trip latency Batch transfers Suitable for use in roaming Per active device state	Not robust against device reboot, network failures*
Event-driven polling	Batch transfers Suitable for use in roaming Per active device state	Not robust against device reboot, network failures* Two round-trip latency

Key
* = addressed by non-volatile storage

3. Review of Accounting Protocols

Accounting systems have been successfully implemented using protocols such as RADIUS, TACACS+, and SNMP. This section describes the characteristics of each of these protocols.

3.1. RADIUS

RADIUS accounting, described in [4], was developed as an add-on to the RADIUS authentication protocol, described in [3]. As a result, RADIUS accounting shares the event-driven approach of RADIUS authentication, without support for batching or polling. As a result, RADIUS accounting scales with the number of accounting events instead of the number of devices, and accounting transfers are inefficient.

Since RADIUS accounting is based on UDP and timeout and retry parameters are not specified, implementations vary widely in their approach to reliability, with some implementations retrying until delivery or buffer exhaustion, and others losing accounting data after a few retries. Since RADIUS accounting does not provide for application-layer acknowledgments or error messages, a RADIUS Accounting-Response is equivalent to a transport-layer acknowledgment and provides no protection against application layer malfunctions. Due to the lack of reliability, it is not possible to do simultaneous usage control based on RADIUS accounting alone. Typically another device data source is required, such as polling of a session MIB or a command-line session over telnet.

RADIUS accounting implementations are vulnerable to packet loss as well as application layer failures, network failures and device reboots. These deficiencies are magnified in inter-domain accounting as is required in roaming ([1],[2]). On the other hand, the event-driven approach of RADIUS accounting is useful where low processing delay is required, such as credit risk management or fraud detection.

While RADIUS accounting does provide hop-by-hop authentication and integrity protection, and IPSEC can be employed to provide hop-by-hop confidentiality, data object security is not supported, and thus systems based on RADIUS accounting are not capable of being deployed with untrusted proxies, or in situations requiring auditability, as noted in [2].

While RADIUS does not support compression, IP compression, described in [5], can be employed to provide this. While in principle extensible with the definition of new attributes, RADIUS suffers from the very small standard attribute space (256 attributes).

3.2. TACACS+

TACACS+ offers an accounting model with start, stop, and interim update messages. Since TACACS+ is based on TCP, implementations are typically resilient against packet loss and short-lived network partitions, and TACACS+ scales with the number of devices. Since TACACS+ runs over TCP, it offers support for both transport layer and application layer acknowledgments, and is suitable for simultaneous usage control and handling of accounting events that require moderate though not the lowest processing delay.

TACACS+ provides for hop-by-hop authentication and integrity protection as well as hop-by-hop confidentiality. Data object security is not supported, and therefore systems based on TACACS+ accounting are not deployable in the presence of untrusted proxies. While TACACS+ does not support compression, IP compression, described in [5], can be employed to provide this.

3.3. SNMP

SNMP, described in [19],[27]-[41], has been widely deployed in a wide variety of intra-domain accounting applications, typically using the polling data collection model. Polling allows data to be collected on multiple accounting events simultaneously, resulting in per-device state. Management applications are able to retry requests when a response is not received, providing resiliency against packet loss or even short-lived network partitions. Implementations without non-volatile storage are not robust against device reboots or network failures, but when combined with non-volatile storage they can be made highly reliable.

SMIv1, the data modeling language of SNMPv1, has traps to permit trap-directed polling, but the traps are not acknowledged, and lost traps can lead to a loss of data. SMIv2, used by SNMPv2c and SNMPv3, has Inform Requests which are acknowledged notifications. This makes it possible to implement a more reliable event-driven polling model or event-driven batching model. However, we are not aware of any SNMP-based accounting implementations currently built on the use of Informs.

3.3.1. Security services

SNMPv1 and SNMPv2c support per-packet authentication and read-only and read-write access profiles, via the community string. This clear-text password approach provides only trivial authentication, and no per-packet integrity checks, replay protection or confidentiality. View-based access control [40] can be supported using the snmpCommunityMIB, defined in [11], and SNMPv1 or SNMPv2c

messages. The updated SNMP architecture [rfc2571] supports per-packet hop-by-hop authentication, integrity and replay protection, confidentiality and access control.

The SNMP User Security Model (USM) [38] uses shared secrets, and when the product of the number of domains and devices is large, such as in inter-domain accounting applications, the number of shared secrets can get out of hand. The localized key capability in USM allows a manager to have one central key, sharing it with many SNMP entities in a localized way while preventing the other entities from getting at each other's data. This can assist in cross-domain security if deployed properly.

SNMPv3 does not support end-to-end data object integrity and confidentiality; SNMP proxy entities decrypt and re-encrypt the data they forward. In the presence of an untrusted proxy entity, this would be inadequate.

3.3.2. Application layer acknowledgments

SNMP uses application-layer acknowledgment to indicate that data has been processed. SNMP Responses to get, get-next, or get-bulk requests return the requested data, or an error code indicating the nature of the error encountered.

A noError SNMP Response to a SET command indicates that the requested assignments were made by the application. SNMP SETs are atomic; the command either succeeds or fails. An error-response indicates that the entity received the request, but did not succeed in executing it.

Notifications do not use acknowledgements to indicate that data has been processed. The Inform notification returns an acknowledgement of receipt, but not of processing, by design. Since the updated SNMP architecture treats entities as peers with varying levels of functionality, it is possible to use SETs in either direction between cooperating entities to achieve processing acknowledgements.

There are eighteen SNMP error codes. The design of SNMP makes service-specific error codes unnecessary and undesirable.

3.3.3. Proxy forwarders

In the accounting management architecture, proxy forwarders play an important role, forwarding intra and inter-domain accounting events to the correct destinations. The proxy forwarder may also play a role in a polling or event-driven polling architecture.

The functionality of an SNMP Proxy Forwarder is defined in [39]. For example, the network devices may be configured to send notifications for all domains to the Proxy Forwarder, and the devices may be configured to allow the Proxy Forwarder to access all MIB data.

The use of proxy forwarders may reduce the number of shared secrets required for inter-domain accounting. With Proxy Forwarders, the domains could share a secret with the Proxy Forwarder, and in turn, the Proxy Forwarder could share a secret with each of the devices. Thus the number of shared secrets will scale with the sum of the number of devices and domains rather than the product.

The engine of an SNMP Proxy Forwarder does not look inside the PDU of the message except to determine to which SNMP engine the PDU should be forwarded or which local SNMP application should process the PDU. The SNMP Proxy Forwarder does not modify the varbind values; it does not modify the varbind list except to translate between SNMP versions; and it does not provide any varbind level access control.

3.3.4. Domain-based access controls in SNMP

Domain-based access controls are required where multiple administrative domains are involved, such as in the shared use networks and roaming associations described in [1]. Since the same device may be accessed by multiple organizations, it is often necessary to control access to accounting data according to the user's organization. This ensures that organizations may be given access to accounting data relating to their users, but not to data relating to users of other organizations.

In order to apply domain-based access controls, in inter-domain accounting, it is first necessary to identify the data subset that is to have its access controlled. Several conceptual abstractions are used for identifying subsets of data in SNMP. These include engines, contexts, and views. This section describes how this functionality may be applied in intra and inter-domain accounting.

3.3.4.1. Engines

The new SNMP architecture, described in [27], added the concept of an SNMP engine to improve mobility support and to identify which data source is being referenced. The engine is the portion of an SNMP entity that constructs messages, provides security functions, and maps to the transport layer. Traditional agents and traditional managers each contain an SNMP engine. engineID allows an SNMP engine to be uniquely identified, independent of the address where it is attached to the network.

A securityEngineID field in a message identifies the engine which provides access to the security credentials contained in the message header. A contextEngineID field in a message identifies the engine which provides access to the data contained in the PDU.

The SNMPv3 message format explicitly passes both. In SNMPv1 and SNMPv2c, the data origin is typically assumed to be the communications endpoint (SNMP agent). SNMPv1 and SNMPv2c messages contain a community name; the community name and the source address can be mapped to an engineID via the snmpCommunityTable, described in [11].

3.3.4.2. Contexts

Contexts are used to identify subsets of objects, within the scope of an engine, that are tied to instrumentation. A contextName refers to a particular subset within an engine.

Contexts are commonly tied to hardware components, to logical entities related to the hardware components, or to logical services. For example, contextNames might include board5, board7, repeater1, repeater2, etc.

An SNMP agent populates a read-only dynamic table to tell the manager what contexts it recognizes. Typically contexts are defined by the agent rather than the manager since if the manager defined them, the agent would not know how to tie the contexts to the underlying instrumentation. It is possible that MIB modules could be defined to allow a manager to assign contextNames to a logical subset of instrumentation.

While each context may support instances of multiple MIB modules, each contextName is limited to one instance of a particular MIB module. If multiple instances of a MIB module are required per engine, then unique contextNames must be defined (e.g. repeater1, repeater2). The default context "" is used for engines which only support single instances of MIB modules, and it is used for MIB modules where it only makes sense to have one instance of that MIB module in an engine and that instance must be easy to locate, such as the system MIB or the security MIBs.

SNMPv3 messages contain contextNames which are limited to the scope of the contextEngineID in the message. SNMPv1 and SNMPv2c messages contain communities which can be mapped to contextNames within the local engine, or can be mapped to contextNames within other engines via the snmpCommunityTable, described in [11].

3.3.4.3. Views

Views are defined in the View-based Access Control Model. A view is a mask which is used to determine access to the managed objects in a particular context. The view identifies which objects are visible, by specifying OIDs of the subtrees included and excluded. There is also a mechanism to allow wildcards in the OID specification.

For example, it is possible to define a view that includes RMON tables, and another view that includes only the SNMPv3 security related tables. Using these views, it is possible to allow access to the RMON view for users Joe and Josephine (the RMON administrators), and access to the SNMPv3 security tables for user Adam (the SNMP security Administrator).

Views can be set up with wildcards. For a table that is indexed using IP addresses, Joe can be allowed access to all rows in given RMON tables (e.g. the RMON hostTable) that are in the subnet 10.2.x.x, while Josephine is given access to all rows for subnet 10.200.x.x.

Views filter at the name level (OIDs), not at the value level, so defining views based on the values of non-index data is not supported. In this example, were the IP address to have been used merely as a data item rather than an index, it would not be possible to utilize view-based access control to achieve the desired objective (delegation of administrative responsibility according to subnet).

View-based access control is independent of message version. It can be utilized by entities using SNMPv1, SNMPv2c, or SNMPv3 message formats.

3.3.5. Inter-domain access-control alternatives

As the number of network devices within the shared use or roaming network grows, the polling model of data collection becomes increasingly impractical since most devices will not carry data relating to the polling organization. As a result, shared-use networks or roaming associations relying on SNMP-based accounting have generally collected data for all organizations and then sorted the resulting session records for delivery to each organization. While functional, this approach will typically result in increased processing delay as the number of organizations and data records grows.

This issue can be addressed in SNMP using the event-driven, event-driven polling or event-driven batching approaches. Traps and Informs permit SNMP-enabled devices to notify domains that have

accounting data awaiting collection. SNMP Applications [39] defines a standard module for managing notifications.

To use the event-driven approaches, the device must be able to determine when information is available for a domain. Domain-specific data can be differentiated at the SNMP agent level through the use of the domain as an index, and the separation of data into domain-specific contexts.

3.3.5.1. Domain as index

View-based access control [40] allows multiple fine-grained views of an SNMP MIB to be assigned to specific groups of users, such that access rights to the included data elements depend on the identity of the user making the request.

For example, all users of bigco.com which are allowed access to the device would be defined in the User-based security MIB module (or other security model MIB module). For simplicity in administering access control, the users can be grouped using a vacmGroupName, e.g. bigco. A view of a subset of the data objects in the MIB can be defined in the vacmViewFamilyTreeTable. A vacmAccessTable pairs groups and views. For messages received from users in the bigco group, access would only be provided to the data permitted to be viewed by bigco users, as defined in the view family tree. This requires that each domain accessing the data be given one or more separate vacmGroupNames, an appropriate ViewTable be defined, and the vacmAccessTable be configured for each group.

Views filter at the name (OID) level, not at the data (value) level. When using views to filter by domain it is necessary to use the domain as an index. Standard view-based access control is not designed to filter based on the values on non-indexed fields.

For example, a table of session data could be indexed by record number and domain, allowing a view to be defined that could restrict access to bigco data to the administrators of the bigco domain.

An advantage of using domains as an index is that this technique can be used with SNMPv1 and SNMPv2c agents as well as with SNMPv3 agents. A disadvantage is that the MIB modules must be specifically designed for this purpose. Since existing MIB modules rarely use the domain as an index, domain separation cannot be enabled within legacy MIB modules using this technique.

SNMP does support a RowPointer convention that could be used to define a new table, indexed by domain, which holds tuples between the domain and existing rows of data. This would introduce issues of

synchronization between tables.

3.3.5.2. Contexts

ContextNames can be used to differentiate multiple instances of a MIB module within an engine.

Individual domains, such as bigco.com, could be mapped to logical contexts, such as a bigco context. The agent would need to create and recognize new contexts and to know which instrumentation is associated with the logical context. The agent needs to collect accounting data by domain and make the data accessible via distinct contexts, so that access control can be applied to the context to prevent disclosure of sensitive information to the wrong domain. The VACM access control views are applied relative to the context, so an operation can be permitted or denied a user based on the context which contains the data.

Domain separation is handled by using contextName to differentiate multiple virtual tables. For example, if accounting data has been collected on users with the bigco.com and smallco.com domains, then a separate virtual instance of the accounting session record table would exist for each domain, and each domain would have a corresponding contextName. When a get-bulk request is made with a contextName of bigco, then data from the virtual table in the bigco context, i.e. corresponding to the bigco.com domain, would be returned.

There are a number of design approaches to creating new contexts and associating the contexts with appropriate instrumentation, most notably a sub-agent approach and a manager-configured MIB approach.

AgentX [51], which standardizes a registration protocol between sub-agents and master agents to simplify SNMP agent implementation, allows for the creation and recognition of new contextNames when a subagent registers to provide support for a particular MIB subtree range. The sub-agent knows how to support a particular functionality, e.g. instrumentation exposed via a range of MIB objects. Based on values detected in the data, such as source=bigco.com, the sub-agent could determine that a new domain needed to be tracked and create the appropriate context for the collection of the data, plus the appropriate access control entries. The determination could be table-driven, using MIB configuration.

A manager-driven approach could use a MIB module to predefine contextNames corresponding to the domains of interest, and to indicate which objects should be collected, how to differentiate to which domain the data should be applied based on a specified

condition, and what access control rules apply to the context.

Either technique could associate existing MIB modules to domain-specific contexts, so domain separation can be applied to MIB modules not specifically designed with domain separation in mind. Legacy agents would not be designed to do this, so they would need to be updated to support inter-domain separation and VACM access control.

The use of contextNames for inter-domain separation represents new territory, so careful consideration would be needed in designing the MIB modules and applications to provide domain to context and context to instrumentation mappings, and to ensure that security is not weakened.

3.3.6. Outstanding issues

There are issues that arise when using SNMP for transfer of bulk data, including issues of latency, network overhead, and table retrieval, as discussed in [49].

In accounting applications, management stations often must retrieve large tables. Latency can be high, even with the get-bulk operation, because the response must fit into the largest supported packet size, requiring multiple round-trips. Transfers may be serialized and the resulting latency will be a combination of multiple round-trip times, possible timeout and re-transmission delays and processing overhead, which may result in unacceptable performance. Since data may change during the course of multiple retrievals, it can be difficult to get a consistent snapshot.

For bulk transfers, SNMP network overhead can be high due to the lack of compression, inefficiency of BER encoding, the transmission of redundant OID prefixes, and the "get-bulk overshoot problem". In bulk transfer of a table, the OIDs transferred are redundant: all OID prefixes up to the column number are identical, as are the instance identifier postfixes of all entries of a single table row. Thus it may be possible to reduce this redundancy by compressing the OIDs, or by not transferring an OID with each variable.

The "get-bulk overshoot problem", described in reference [50], occurs when using the get-bulk PDU. The problem is that the manager typically does not know the number of rows in the table. As a result, it must either request too many rows, retrieving unneeded data, or too few, resulting in the need for multiple get-bulk requests. Note that the "get-bulk overshoot" problem may be preventable on the agent side. Reference [41] states that an agent can terminate the get-bulk because of "local constraints" (see items 1 and 3 on pages 15/16 of [41]). This could be interpreted to mean

that it is possible to stop at the end of a table.

3.3.6.1. Ongoing research

To address issues of latency and efficiency, the Network Management Research Group (NMRG) was formed within the Internet Research Task Force (IRTF). Since the NMRG work is research and is not on the standards track, it should be understood that the NMRG proposals may never be standardized, or may change substantially during the standardization process. As a result, these proposals represent works in progress and are not readily available for use.

The proposals under discussion in the IRTF Network Management Research Group (NMRG) are described in [46]. These include an SNMP-over-TCP transport mapping, described in [47]; SNMP payload compression, described in [48]; and the addition of a "get subtree" PDU or the subtree retrieval MIB [50].

The SNMP-over-TCP transport mapping may result in substantial latency reductions in table retrieval. The latency reduction of an SNMP-over-TCP transport mapping will likely manifest itself primarily in the polling, event-driven polling and event-driven batching modes.

Payload compression methods include compression of the IP packet, as described in [5] or compression of the SNMP payload, described in [48].

Proposed improvements to table retrieval include a subtree retrieval MIB and the addition of a get-subtree PDU. The subtree retrieval MIB [50] requires no changes to the SNMP protocol or SNMP protocol engine, so it can be implemented and deployed more easily than a change to the protocol. The addition of a get-subtree PDU implies changes to the protocol and to the engines of all SNMP entities which would support it. Since it may be possible to address the "get-bulk overshoot problem" without changes to the SNMP protocol, the necessity of this modification is controversial.

Reference [49] also discusses file-based storage of SNMP data, and use of an FTP MIB, to enable storage of SNMP data in non-volatile storage, and subsequent bulk transfer via FTP. This approach would require implementation of additional MIB modules as well as FTP, and requires separate security mechanisms such as IPSEC to provide authentication, replay, integrity protection and confidentiality for the data in transit. The file-based transfer approach has an important benefit - compatibility with non-volatile storage.

Issues of legacy support exist with the NMRG proposals. Devices which do not implement the new functionality would need to be accommodated. This is especially problematic for proxy forwarders, which may need to act as translators between new and legacy entities. In these situations, the overhead of translation may offset the benefits of the new technologies.

3.3.6.2. On-going security extension research

In order to simplify key management and enable use of certificate-based security in SNMPv3, a Kerberos Security Model (KSM) for SNMPv3 has been proposed in [44]. This memo is not on the standards track, and therefore is not yet readily available for use.

Use of Kerberos with SNMPv3 requires storage of a key on the KDC for each device and domain, while dynamically generating a session key for conversations between domains and devices. In terms of stored keys, the KSM approach scales with the sum of devices and domains; in terms of dynamic session keys, it scales as the product of domains and devices.

As Kerberos is extended to allow initial authentication via public key, as described in [42], and cross-realm authentication, as described in [43], the KSM inherits these capabilities. As a result, this approach may have potential to reduce or even eliminate the shared secret management problem. However, it should also be noted that certificate-based authentication can strain the limits of UDP packet sizes supported in SNMP implementations, so that alternate transport mappings may be required to support this.

An IPSEC-based security model for SNMPv3 has been discussed. Implementation of such a security model would require the SNMPv3 engine to be able to retrieve the properties of the IPSEC security association used to protect the SNMPv3 traffic. This would include the security services invoked, as well as information relating to the other endpoint, such as the authentication method and presented identity and certificate. To date such APIs have not been widely implemented, and in addition, most IPSEC implementations only support machine certificates, which may not provide the required granularity of identification. Thus, an IPSEC-based security model for SNMPv3 would probably take several years to come to fruition.

3.3.7. SNMP summary

Given the wealth of existing accounting-related MIB modules, it is likely that SNMP will remain a popular accounting protocol for the foreseeable future.

Support for notifications makes it possible to implement the event-driven, event-driven polling and event-driven batching models. This makes it possible to notify domains of available data rather than requiring them to poll for it, which is critical in shared use networks and roaming.

Given the SNMPv3 security enhancements, it is desirable for SNMP-based intra-domain accounting implementations to upgrade to SNMPv3. Such an upgrade is virtually mandatory for inter-domain applications.

In inter-domain accounting, the burden of managing SNMPv3 shared secrets can be reduced via the localized key capability or via implementation of a Proxy Forwarder. In the long term, alternative security models such as the Kerberos Security Model may further reduce the effort required to manage security and enable streamlined inter-domain operation.

SNMP-based accounting has limitations in terms of efficiency and latency that may make it inappropriate for use in situations requiring low processing delay or low overhead. This includes usage sensitive billing applications where fraud detection may be required. These issues can be addressed via proposals under discussion in the IRTF Network Management Research Group (NMRG). The experimental SNMP over TCP transport mapping may prove helpful at reducing latency. Depending on the volume of data, some form of compression may also be worth considering. However, since these proposals are still in the research stage, and are not on the standards track, these capabilities are not readily available, and the specifications could change considerably before they reach their final form.

SNMP supports separation of accounting data by domain, using either of two general approaches with the VACM access control model. The domain as index approach can be used if the desired MIB module supports domain indexing, or it can implemented using an additional table. The domain-context approach can be used in agents which support dynamic logical contexts and a domain-to-context and context-to-instrumentation mapping mechanism. Either approach can be supported using SNMPv1, SNMPv2c, or SNMPv3 messages, by utilizing the snmpCommunitytable [11] to provide a community-to-context mapping.

4. Review of Accounting Data Transfer

In order for session records to be transmitted between accounting servers, a transfer protocol is required. Transfer protocols in use today include SMTP, FTP, and HTTP. For a review of accounting attributes and record formats, see [45].

Reference [49] contains a discussion of alternative encodings for SMI data types, as well as alternative protocols for transmission of accounting data. For example, [49] describes how MIME tags and XML DTDs may be used for encoding of SNMP messages or SMI data types. This enables data from SNMP MIBs to be transported using any protocol that can encapsulate MIME or XML, including SMTP and HTTP.

4.1. SMTP

To date, few accounting management systems have been built on SMTP since the implementation of a store-and-forward message system has traditionally required access to non-volatile storage which has not been widely available on network devices. However, SMTP-based implementations have many desirable characteristics, particularly with regards to security.

Accounting management systems using SMTP for accounting transfer will typically support batching so that message processing overhead will be spread over multiple accounting records. As a result, these systems result in per-active device state. Since accounting systems using SMTP as a transfer mechanism have access to substantial non-volatile storage, they can generate, compress if necessary, and store accounting records until they are transferred to the collection site. As a result, accounting systems implemented using SMTP can be highly efficient and scalable. Using IPSEC, TLS or Kerberos, hop-by-hop security services such as authentication, integrity protection and confidentiality can be provided.

As described in [13] and [15], data object security is available for SMTP, and in addition, the facilities described in [12] make it possible to request and receive signed receipts, which enables non-repudiation as described in [12]-[17]. As a result, accounting systems utilizing SMTP for accounting data transfer are capable of satisfying the most demanding security requirements. However, such systems are not typically capable of providing low processing delay, although this may be addressed by the enhancements described in [20].

4.2. Other protocols

File transfer protocols such as FTP and HTTP have been used for transfer of accounting data. For example, Reference [9] describes a means for representing ASN.1-based accounting data for storage on archival media. Through the use of the Bulk File MIB, accounting data from an SNMP MIB can be stored in ASN.1, bulk binary or Bulk ASCII format, and then subsequently retrieved as required using the FTP Client MIB.

Given access to sufficient non-volatile storage, accounting systems based on record formats and transfer protocols can avoid loss of data due to long-duration network partitions, server failures or device reboots. Since it is possible for the transfer to be driven from the collection site, the collector can retry transfers until successful, or with HTTP may even be able to restart partially completed transfers. As a result, file transfer-based systems can be made highly reliable, and the batching of accounting records makes possible efficient transfers and application of required security services with lessened overhead.

5. Summary

As noted previously in this document, accounting applications vary in their security and reliability requirements. Some uses such as capacity planning may only require authentication, integrity and replay protection, and modest reliability. Other applications such as inter-domain usage-sensitive billing may require the highest degree of security and reliability, since in these cases the transfer of accounting data will lead directly to the transfer of funds.

Since accounting applications do not have uniform security and reliability requirements, it is not possible to devise a single accounting protocol and set of security services that will meet all needs. Rather, the goal of accounting management should be to provide a set of tools that can be used to construct accounting systems meeting the requirements of an individual application. As a result, it is important to analyze a given accounting application to ensure that the methods chosen meet the security and reliability requirements of the application.

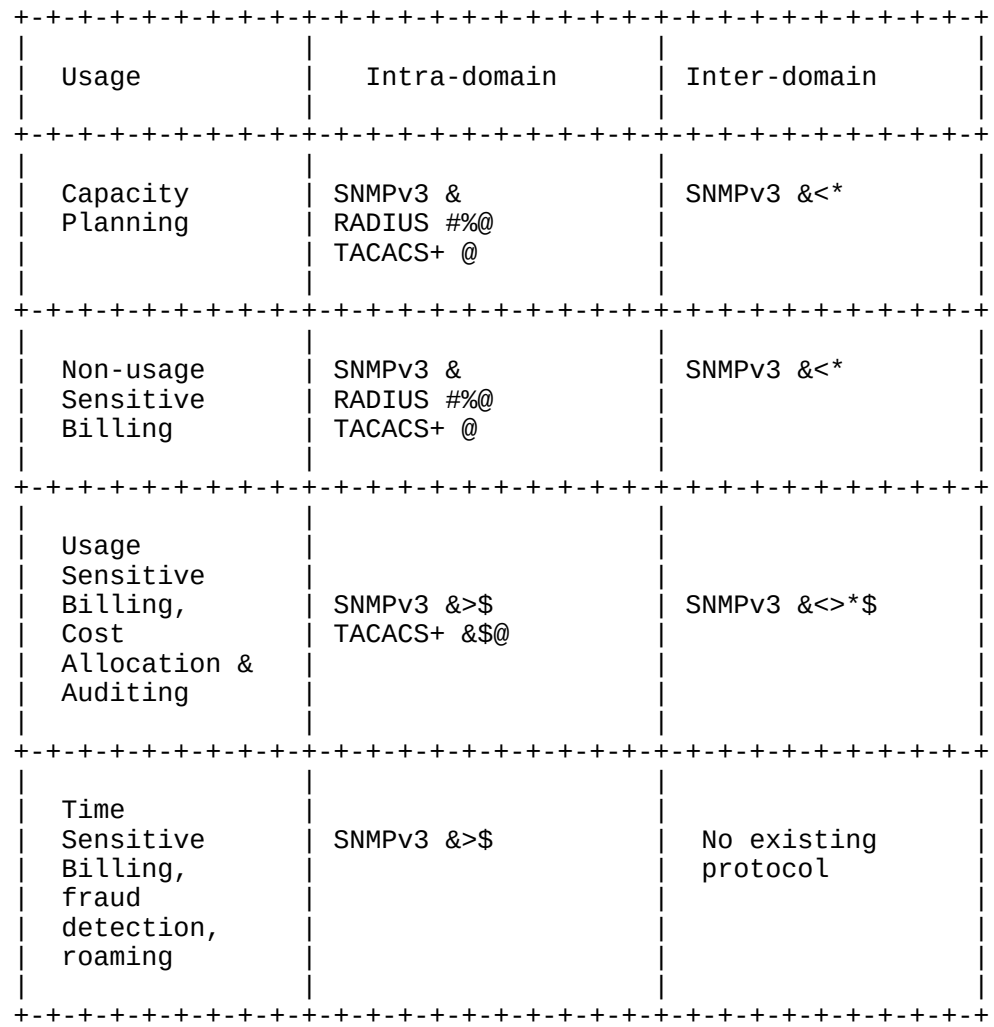
Based on an analysis of the requirements, it appears that existing deployed protocols are capable of meeting the requirements for intra-domain capacity planning and non-usage sensitive billing. In these applications efficient transfer of bulk data is useful although not critical. Thus, it is possible to use SNMPv3 to satisfy these requirements, without the NMRG extensions. These include TCP transport mapping, sub-tree retrieval, and OID compression.

In inter-domain capacity planning and non-usage sensitive billing, the security and reliability requirements are greater. As a result, no existing deployed protocol satisfies the requirements. For example, existing protocols lack data object security support and extensions to improve scalability of inter-domain authentication are needed, such as the Kerberos Security Model (KSM) for SNMPv3.

For usage sensitive billing, as well as cost allocation and auditing applications, the reliability requirement are greater. Here transport layer reliability is required to provide robustness against packet loss, as well as application layer acknowledgments to provide robustness against accounting server failures. SNMP operations with the exception of InforRequest provide application layer acknowledgments, and the TCP transport mapping proposed by NMRG provides robustness against packet loss. Inter-domain operation can benefit from data object security (which no existing protocol provides) as well as inter-domain security model enhancements (such as the KSM).

Where high-value sessions are involved, such as in roaming, Mobile IP, or telephony, it may be necessary to put bounds on processing delay. This implies the need to reduce latency. As a result, the NMRG extensions are required in time sensitive billing applications, including TCP transport mapping, get-subtree capabilities and OID compression. High reliability is also required in this application, implying the need for application layer as well as transport layer acknowledgments. SNMPv3 with the NMRG extensions and security scalability improvements such as the KSM can satisfy the requirements in intra-domain use.

However, in inter-domain use, additional security precautions such as data object security and receipt support are required. No existing protocol can meet these requirements. A summary is given in the table on the next page.



Usage	Intra-domain	Inter-domain
Capacity Planning	SNMPv3 & RADIUS #%@ TACACS+ @	SNMPv3 &<*
Non-usage Sensitive Billing	SNMPv3 & RADIUS #%@ TACACS+ @	SNMPv3 &<*
Usage Sensitive Billing, Cost Allocation & Auditing	SNMPv3 &>$ TACACS+ &$@	SNMPv3 &<>*$
Time Sensitive Billing, fraud detection, roaming	SNMPv3 &>$	No existing protocol

Key
= lacks confidentiality support
* = lacks data object security
% = limited robustness against packet loss
& = lacks application layer acknowledgment (e.g. SNMP InformRequest)
$ = requires non-volatile storage
@ = lacks batching support
< = lacks certificate support (KSM, work in progress)
> = lacks support for large packet sizes (TCP transport mapping, experimental)

6. Security Considerations

Security issues are discussed throughout this memo.

7. Acknowledgments

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