Chapter 4

ATM VP-Based Ring Network

ATM VP-based network architecture is essentially a compromise of the SONET/STM and ATM network architectures: it takes a system simplicity concept from the SONET/STM network and keeps the flexibility of ATM technology. The requirement of flexible bandwidth allocation can be achieved by the inherent characteristic of ATM technology, and the requirement of less expensive ADM's can be achieved by the simplicity of the virtual path concept and its associated nonhierarchical path multiplexing structure.

The SONET ring architecture has been widely accepted by Bellcore Client Companies (BCC's) as a cost-effective, survivable SONET network architecture due to its standard signal interface, economical high-speed signal and drop capability, fast self-healing capability, and simple network operations [4, 13].

Figure 4-1 presents SONET ring only use either the centralized ring grooming or non-demand grooming system, since the distributed ring grooming system at the DS1 (1.554 Mbps) level is too expensive to be implemented.

The centralized ring grooming system, as illustrated in Figure 4-1(a), includes a SONET ring with an ADM in each node. The ADM used in this centralized ring grooming system can be a simple add-drop multiplexer since it doesn't need the grooming capability. The signal add-drop in this case can be implemented by using a time slot assignment (TSA) method that assigns dedicated timeslots for each node and those dedicated timeslots can be dynamically assigned to DS1 ports.

Figure 4-1(b) illustrates the distribution ring grooming system, which demand grooming capability into each ring node by using a Time Slot Interchange (TSI) switching fabric within each ADM. The TSI function in this distribution ring grooming architecture is performed at the VT (DS1) level rather than the STS-1 (51.84Mbps) (DS3) level, as commonly used for self-healing architecture [45]. Compared to the centralized ring grooming system, the distributed ring grooming system generally requires less ring capacity for the same DS1 demand requirement, but at the expensive of more complex and expensive ADM's.

To reduce SONET ring cost, an enhanced grooming system must combine the best features of centralized and distributed ring-grooming systems. In other words, the new more cost effective SONET ring grooming system should have bandwidth allocation flexibility to reduce the ring capacity requirement, as does the distributed ring grooming system using ADM/TSI's and should use simpler and less expensive ADM's like the ADM/TSA. The conceptual diagram for this enhanced SONET ring grooming is depicted in figure 4-1(c).

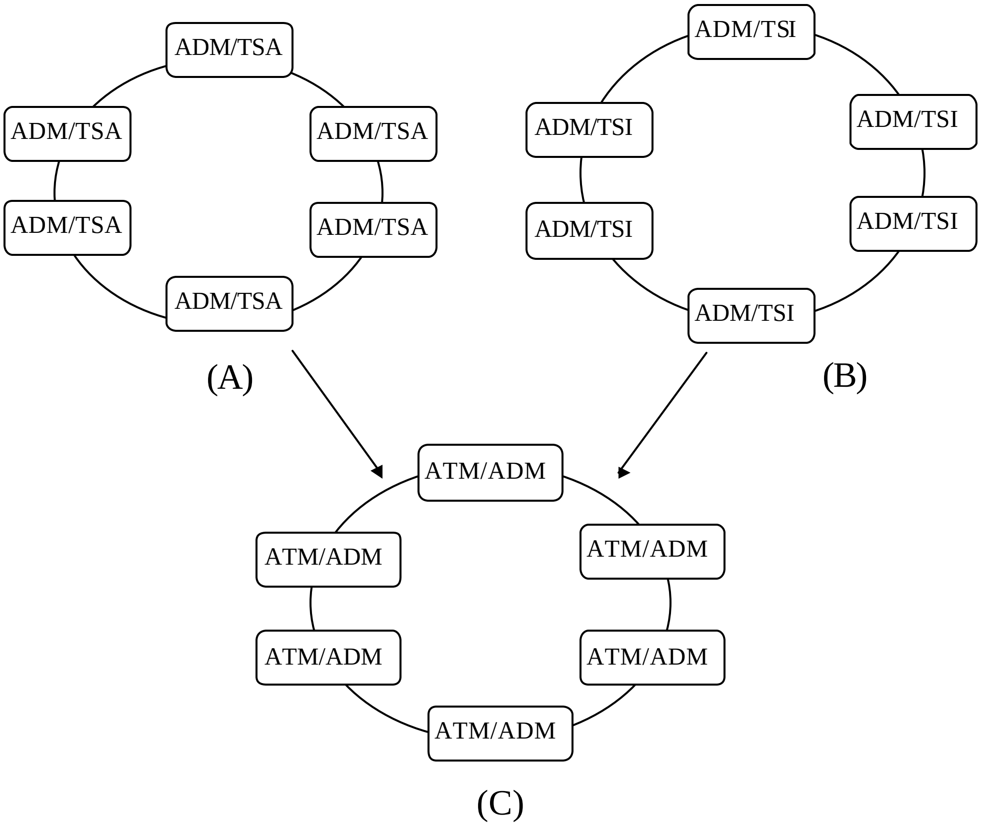


Figure 4-1 SONET Bandwidth Management System (a) Centralized. (b) Distributed. (c) Enhanced ATM system.

4-1 An ATM Ring Architecture Using VP Concepts

The VP concept is primarily used for nodal addressing for supporting different traffics routing. Figure 4-2 depicts a SONET/ATM Ring architecture using Point-to-point VP's (denoted by SARPVP with one direction only). The VP used in the point-to-point VP add-drop multiplexing scheme carries VC connections between the same two ring nodes.

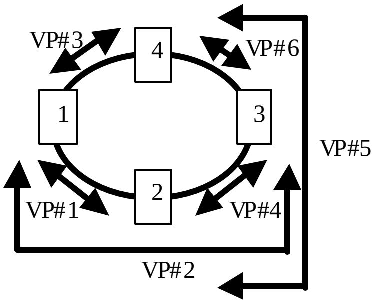


Figure 4-2 An ATM VP Ring Architecture (SARPVP)

In this SARPVP architecture, each ring node pair is preassigned a duplex VP, as shown from Figure 4-2, the VP#2 and VP# $\overline{2}$ (not shown in the Figure) are carrying all VC connections from nodes 1 to 3 and from node 3 to node 1, respectively. The physical route assignment for the VP depends upon the type unidirectional or bidirectional of the considered SONET ring. If the considered ring is a unidirectional ring two diverse routes which form a circle are assigned to each VP. From Figure 4-2, the two physical routes 1-2-3 and 3-4-1 are assigned to VP#2 and VP#2' (not shown in the Figure) that is if the considered ring is unidirectional. If the considered ring is bidirectional, only one route is assigned to each duplex VP (e.g., route 1-2-3 is assigned to both the VP#2 and VP# $\overline{2}$), and demands between nodes 1 and 3 are routed through route 1-2-3 bidirectionally. More details on SONET unidirectional and bidirectional ring architecture can be found in [45, 46].

In order to avoid the VP translation at intermediate ring nodes of VP connection, the VPI value is assigned on a global basis. The ATM cell add-drop or pass-through at each ring node is performed by checking the cell's VPI value. Since the VPI value has global significance and only one route is available for all outgoing cells, it needed not be translated at each intermediate ring node. Thus, no VP cross-connect capability is needed for the ATM/ADM of this SARPVP ring architecture. The ATM ADM for the SARPVP architecture can be implemented in different ways depending on physical SONET STS-Nc terminations.

The global VPI value assignment presents no problem here, since only one route exists for all outgoing ATM cells and the number of nodes supported by a ring is usually limited. For example, the 12-bit VPI field in the Network-to-Network Interface (NNI) ATM cell represents up to 4096 VPI values available for use. Thus, the maximum number of ring nodes is 91; let N be the number of ring nodes. The maximum number of ring nodes is the number satisfying the equation 4-1.

$$[N(N-1)]/2 <= 4096 \quad \text{--} \quad (4\text{-}1)$$

Then the maximum number of nodes is 91; which is enough to practically support BCCs interoffice and loop rings. If the point-to-point VP ring is used to support present DS1 (1.544 Mbps) services (via circuit emulation), each DS1 comprises a VC connection and is assigned a VPI/VCI based on its addressing information and the relative position of the DS1 within all the DS1's terminating at the same source and destination on the ring. For example, VPI= 2 and VCI = 3 represents a DS1 that is the third DS1 of the DS1 group terminating at Node 1 and Node 3.

4- 2 ATM Ring Routing

The physical route assignment for the VP depends upon the type of the considered SONET ring. There are two types, the first one is called unidirectional SONET ring and the second one is called bidirectional SONET ring. In the unidirectional SONET ring, the routing in ATM/ADM node is point-to-point as shown in Figure 4-3.

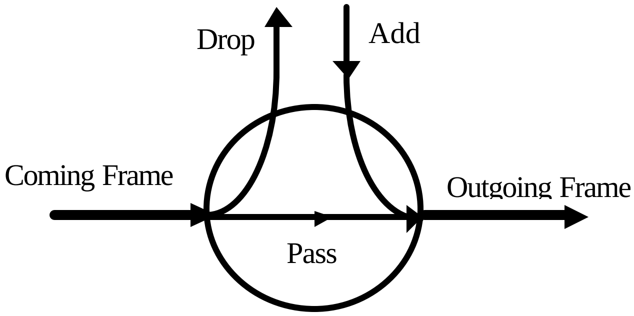


Figure 4-3 ATM/ADM Node in Unidirectional SONET Ring Network

The maximum number of physical hops in the unidirectional SONET ring is (N-1) hops, depending upon the number of nodes (N). By using VPIs, it can define that node as either transit node or terminator node. For example, the node #1 transmits cells to node #2 via the route 1→2. Node #2 transmits cells to node #1 via route 2→3→4→1, obviously that the number of physical hops in a direction is more than in opposite direction, so the time needed to the pair conversation is not equal.

In the bi-directional SONET ring, the routing is point-to-point, as can be noted in an ATM/ADM node shown in Figure 4-4. The maximum number of physical hops is | N/2 | hops, and it is also dependent on the number of nodes (N). Each node has VPIs values counting (N-1) values.

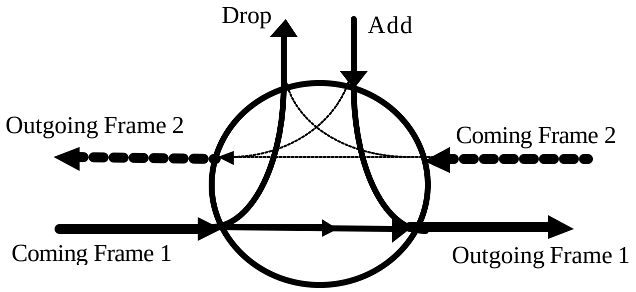


Figure 4-4 ATM/ADM Node in Bidirectional SONET Ring Network

That is lead us to say the direction is forward if it takes the path of (1 → 2→3→…→N), other wise, the direction is reverse if it takes the path (N→ (N-1) →...→3→2→1). If (N-1) is even, the number of VPIs for both forward and reverse directions are equal, but with different values of VPIs, however, there is no VPI has the same value in the ring network. If (N -1) is odd, the number of VPIs in forward direction is more than the number of VPIs in reverse direction by one. The direction that the send cells can follow depends upon the location of source and destination and the number of hops between them the following algorithms are used for these purposes: -

Algorithm 1:

```
Hop_count algorithm ( S: source , D : destination)
    Min = MINMUM (S, D)
    Max = MAXIMUM (S, D)
    if ( $|N/2| >= ( Max - Min)$     hop_count = Max - Min
    Else                    Hop_count = N - ( Max - Min)
```

Algorithm 2:

```
Dir_flag algorithm (S: source, D: destination)
    Min = MINMUM (S, D)
    Max = MAXIMUM (S, D)
    Hop = Hop_count (S, D)
    If (hop = Max - Min)
        If (S < D)    Dir_flag = forward
        Else          Dir_flag = reverse
    If (hop = N - (Max - Min))
        If (S < D)    Dir_flag = reverse
        Else          Dir_flag = forward.
```

Each node can determine its cell direction and the number of hops to other node by using the above algorithm. Finally, we assume that there is a queue for each direction that makes the bidirectional SONET ring works as two separated unidirectional SONET ring. In other word, the bidirectional SONET ring can service number of sources equals to double of the number of sources in the case of unidirectional SONET ring.

In case of the number of nodes is odd, if there are two routing paths available which have the same number of physical hops, it choose the forward direction because that direction is the original direction and it has the highest priority. It is to be noted that, the forward direction is the routing of (1→2→3→...→N), and the reverse direction is the routing of (N → (N-1) →...→3→ 2→1).

4- 3 ATM Add-Drop Multiplexer (ADM) for VP Rings

The ATM/ADM for the SARPVP architecture can be implemented in different ways depending on physical SONET STS-Nc terminations. The most common architectures are in [4]. The ATM STS-Nc terminations are STS-3c, STS-12c, and STS-48c, although only the STS-3c ATM termination has been specified in current CCITT Recommendations.

4-3-1 The Cost Model for SARPVP Ring.

Figure 4-5 depicts a functional diagram for an ATM/ADM STS-3c termination for SARPVP ring. In this Figure, each STS-3c needs a chip to implement a full-duplex ATM and SONET interface function, and a chip for the ATM header processor (checking VPI values and idle cells).

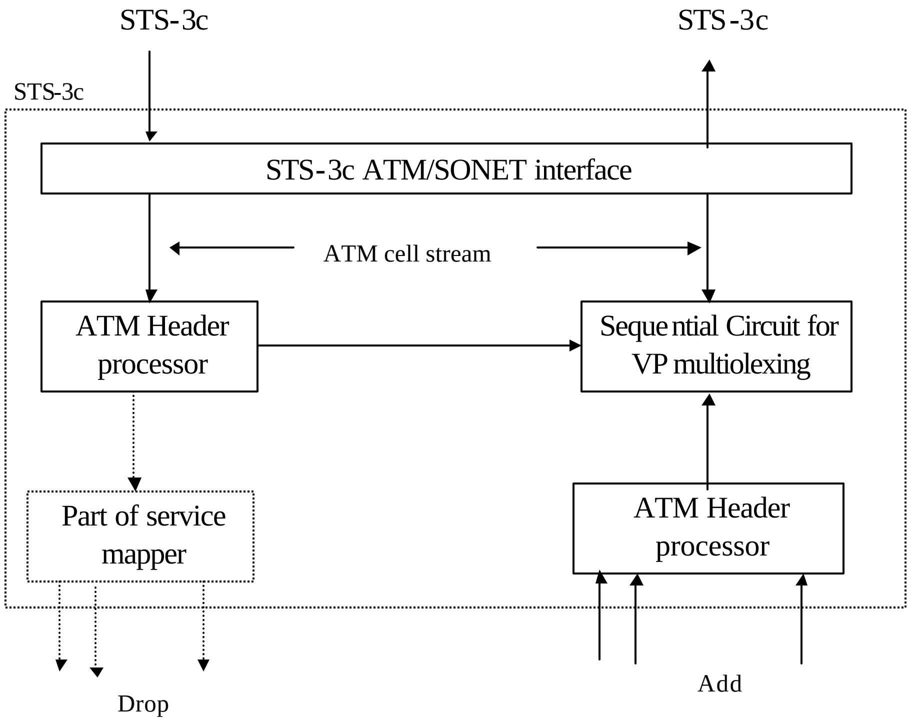


Figure 4-5 STS-3c Chip Count Model for the SARPVP Ring.

A chip performing ATM cell processing for added cells is also needed. A chip is needed for the sequential access protocol for VP multiplexing. Thus, each STS-3c termination requires four chips to the necessary VP add-drop functions. Each STS-3c payload may carry up to 86 DS1 for circuit emulation as computed below. The cell format for DS1 circuit emulation (i.e., Class I in the AAL layer) is depicted in Figure 4-6. In this Figure, each ATM cell has a fixed length of 53 bytes. There are five bytes for the ATM layer overhead and one additional byte is needed for cell sequencing and its protection. Thus, only 47 bytes are available for carrying DS1 service demands.

5 bytes	4 bit	4 bit	47 bytes
Header	SN	SNP	SAR-SDU

SN : Sequence Number.
SNP : Sequence Number Protection.
SAR : Segmentation and Reassembly.
SDU : Service Data Unit.

Figure 4-6, ATM Cell Format for DS1 Circuit Emulation.

Thus, the maximum number of DS1's that can be carried by each STS-3c payload is calculated by equation 4-2 [4].

$$\text{Max. number of DS1's} = \left| \frac{(T\_Rate)\, x\, (R\_Frame)\, x\, (R\_Cell)}{DS1} \right| =$$

$$= \left| \frac{155.52\, x\, \frac{260}{270}\, x\, \frac{47}{53}}{1.544} \right| = 86 \qquad \text{----------------} \quad (4\text{-}2)$$

T_Rate : Transmission data rate in Mbps
R_Frame : Ratio of transmission frame payload to transmission frame
R_Cell : Ratio of cell payload to cell.

Note that, 260/270 is the ratio of non-SONET overhead bytes to the SONET frame size for a STS-3c, and 47/53 is the ratio of payload information field to the ATM cell size. Finally, the ratio of payload to the frame size equals to (260/270) x (47/53), thus the payload is equal to 155.52 times the fraction of payload. Thus, the maximum number of DS1 in STS-3c is equal to the fraction of data rate line (payload) over data rate of each DS1 (1.544 Mbps). We can also define the maximum number of sources by the previous equation, the 1.544 Mbps is replaced by the source rate.

4-3-2 ATM/ADM for SARPVP Ring

Figure 4-7 depicts a possible ADM configuration with STS-3c termination for a SARPVP ring implementation that supports many services via circuit emulation. The ATM VP add-drop function, which is performed at the STS-3c level, requires three major modules.

The **first module** is the ATM/SONET interface, which converts the STS-3c payload to an ATM cells stream and vice versa. The functions performed in this module include all delineation, self-synchronization, and scrambling. The scramble process here is to increase the security and robustness of the cell delineation process against malicious users or unintended simulations of a cell header followed by a correct Header Error Control (HEC) in the information field. This mechanism is required for ATM cell delineation.

The **second module** is to perform header processing, which includes cell addressing (VPI in this case) and HEC. In order to perform cell add-drop/pass-through, this module checks VPI value of each cell to determine if it should be dropped or passed through. This module also identifies idle cells which can be used to insert cells from the considered office (i.e. signal adding) via a simple sequential access protocol. This sequential access protocol can be implemented by the third module that passes through each nonidle cell and inserts the added cells from each queue into outgoing idle cells in a sequential order.

The **third module** is the sequential access protocol that passes through each nonidle cell and insert the added cells into outgoing idle cells in a sequential order. The third functional module also includes a service-mapping module that maps ATM cells to their corresponding destination cards based on VPI/VCI values of ATM cells. This service distributes ATM cells to corresponding groups according to their VPI values. For each group, the ATM cells are further divided and distributed to the corresponding cards by checking their VCI values. This service-mapping module essentially just performs a simple VPI/VCI comparison function.

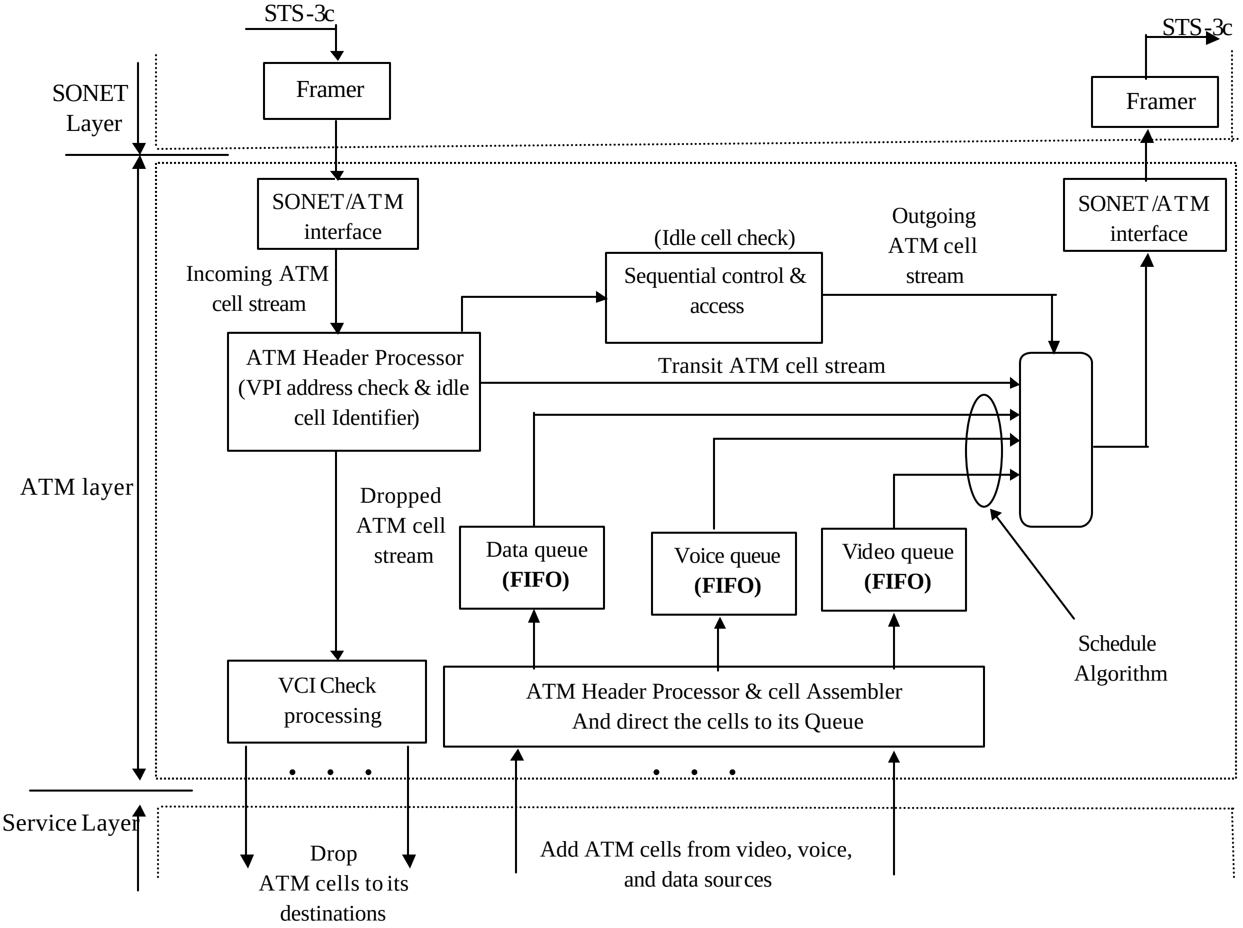


Figure 4-7 An STS-3c Add-Drop Hardware Configuration for the SARPVP Ring

4-4 The Queue Model in **ATM ADM** *Node.*

4-4-1 Queue Model for One Traffic.

This subsection describes the queue model for one queue to each source within the node and a single queue for the node as shown in Figure 4-8. The coming cell to the input of the queue has longer waiting time from all the sources. Clearly that all the cells entered to the input queue of the node are mixed from different sources and service as FIFO.

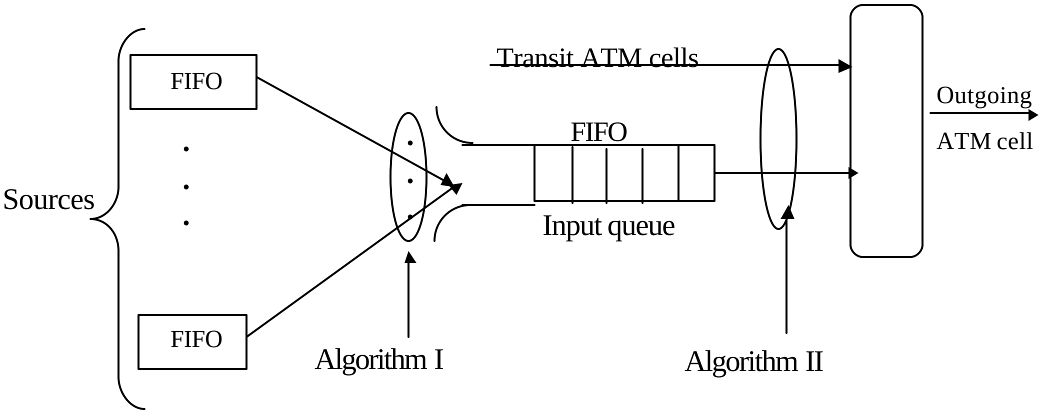


Figure 4-8 Queue Model of ATM/ADM Node.

Two algorithms are used with that queue model as shown in Figure 4-8. Algorithm I, determines which cell has longest waiting time to enter into the input queue of the node. Algorithm II, determines the number of transit ATM cells, and completes the stream flow from the input queue, the following steps describe the two algorithms:

Algorithm I:

```
1- Determine the longest waiting time cell from the whole sources within the
   node.
2- Push these cell in the input queue of the node.
3- Go top step 1.
```

Algorithm II:

```
1- Get transit ATM cell.
2- Determine the number of transit ATM cells.
3- If  (the number of transit cells < the frame size in cells)
   Then, Add cells from input queue to complete the frame.
   Else, No addition.
4- Transmit stream of cells as Frame size cells.
5- Go to step 1.
```

4-4-2 Queue Model for More Than Traffic

This subsection describes the queue model for more than traffic with a single input queue of a particular node. There are three kinds of control methods, described in details in [1].

First method: Single Queue method (SQ). The cells are arriving from various sources in a mixed way and entered to the input queue and processed by FIFO rule.

Second method: Band Division method (BD). Here the band is divided and allocated before hand to various kinds of medium and the cells from a single kind of medium utilize the allocated semi-fixed bandwidth (corresponding to the virtual path).

In this method, the model contains the dedicated queue and server for each medium, as shown in Figure 4-9, FIFO processing is applied to each medium. In Figure 4-7, the sum of the processing powers of the servers is kept constant since it corresponds to the total bandwidth of the transmission channel.

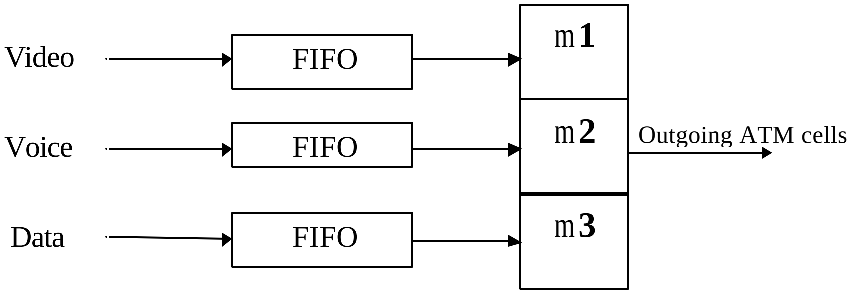


Figure 4-9 Queuing Model of BD Method.

Third method: Priority Queue Control method (PQC). The queue in this method, is provided for each medium and the number of cells to be picked up from the queue is specified with their the priority. This method can be modeled as the multiple queues, as shown in Figure 4-10.

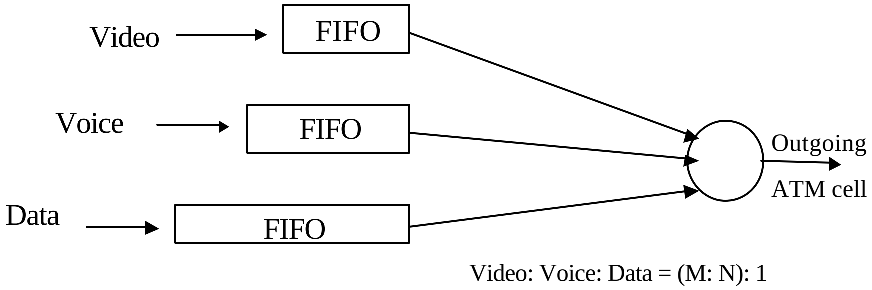


Figure 4-10 Queuing Model of PQC Method

The processing rule in each queue is FIFO. The method is divided into the following two:

1- **video cell exhaustive method:** As shown in the Figure 4-11, the video cell is processed as long as a cell exists in the video queue. If the video queue becomes empty, the voice and data cells are processed alternately.

2- **processing ratio control method**: In this method, the number of cells to be picked up from the queue corresponding to each medium is determined as following.

- *For the voice and the video cells with severe requirements for the delay, the ratio of cells picked up from the queues is set as* $N : M$ *when either of the queues becomes empty, the cells are only picked up from the other queue for service.*
- *Only, if both of the aforementioned queues are empty, a cell picked up from the data queue.*

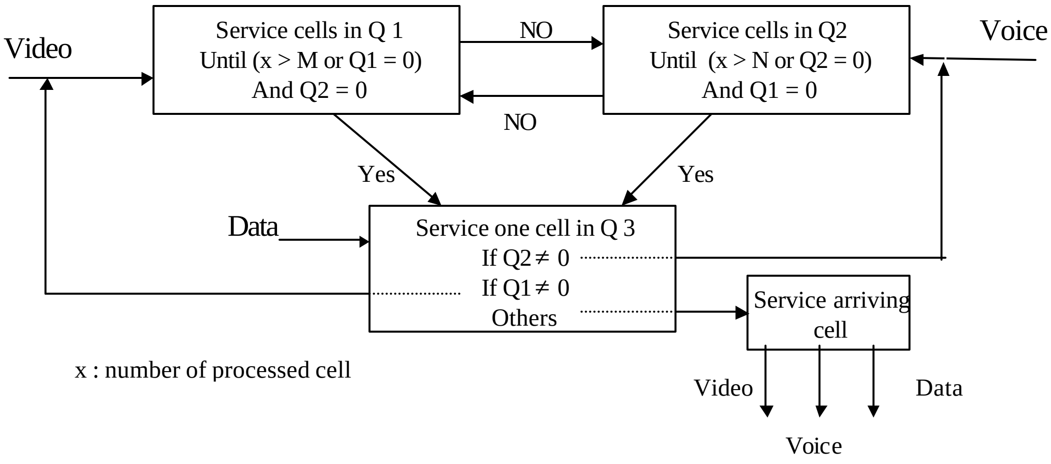


Figure 4-11 Processing Discipline Algorithm

4-4-3 The Proposed Control Method.

In the previous control methods [1], there are fixed ratio among traffics along the service time. That is caused some weak results when the data traffic offered load is dominant than the video and the voice traffics, resulting in unfairness among the traffic and the cells which were picked up from the queue corresponding to each traffic. The following algorithms proposed to overcome this problem:

* *Let the number of cells to be picked up from Video, Voice and Data queues is M: N: D respectively.*

* *To determine the ratios of all traffics, you should follow the next.*

1. *Gets min = Minimum offered load of all applied traffics.*
2. *Set M = Video offered load / min.*
3. *Set N = Voice offered load / min.*
4. *Set D = Data offered load / min.*

The proposed control mechanism method [47] provides the network to service fairly among all the applied traffics. However if the offered load of all traffics is equal, then the ratio will be 1: 1: 1 for Video, Voice, and Data respectively. Figure 4-12, shows the processing algorithm of the proposed control mechanism method.

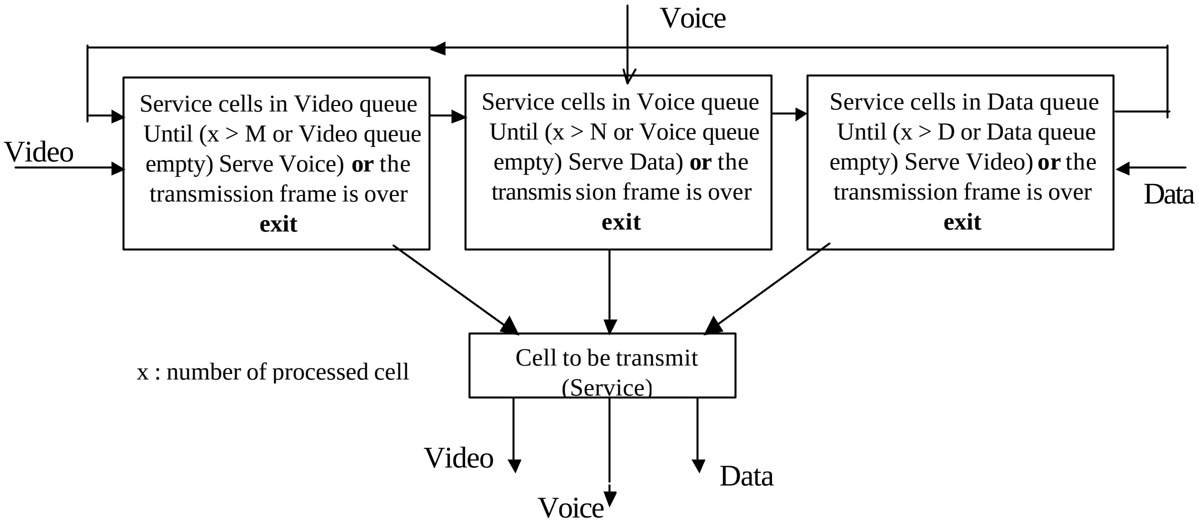


Figure 4-12 Processing Discipline Proposed Algorithm

If there are only two traffic such as video and data and their offered load are 0.25 and 0.10 respectively, then the ratio will be 2: 1 for video and data respectively. On the contrary, if the offered load of video and data are 0.10 and 0.25 respectively, then the ratio will be 1: 2 for video and data respectively. So we can say that the proposed control mechanism method has priority to the traffic within the node. However, with the proposed control mechanism method the node picks up cells from video queue, before picking up cells of voice and data queues. Also, the node picks up cells from voice queue, before picking up cells of data queue. Finally, we can say that the video traffic has higher priority than voice traffic and the voice traffic has higher priority than data traffic. It is to be mention here that is all the above depends upon the offered load of each traffic and the control mechanism method.

4-5 Proposed Fair Organizer for Calling

The VP concept is primarily used to nodal addressing for supporting different traffics routing. The VP used in the point-to-point VP add-drop multiplexing scheme carries VC connections between the same two ring nodes.

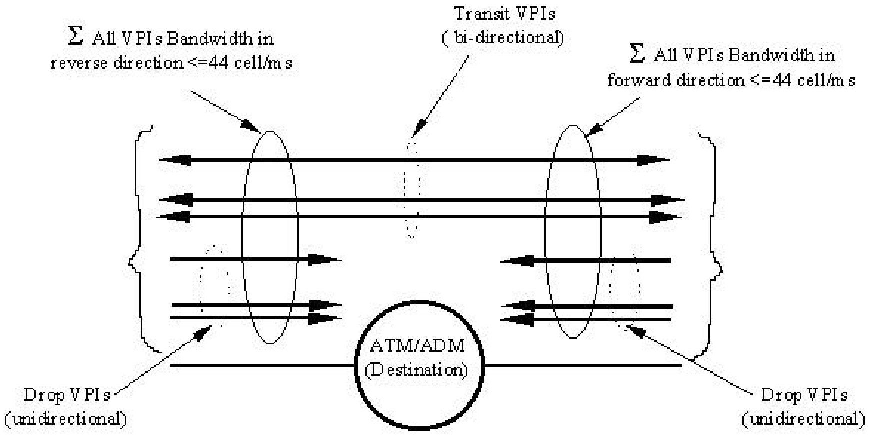


Figure 4-13 the VPIs of ATM/ADM

Figure 4-13 illustrates VPIs of ATM/ADM and the bandwidth in each direction. Each node has two types of VPI, transit VPIs that are in bidirectional and drop VPIs that has different VPI values. The sum of VPI bandwidths in physical link is not more than 44 cell/ms, each node, in the network of N nodes, has (N-1) drop VPI because the ATM ring network is point-to-point connection. The whole drop VPIs are not in the same direction but some in the forward direction and the other in the reverse direction. The number of drop VPIs in both directions depends on the number of nodes in the ATM ring network (i.e. if N is odd, the number of drop VPIs in both directions is the same. If N is even, the number of drops VPIs in forward direction is more than number of drops VPIs in reverse direction by one). In order to define the number of drop VPI in each direction and the number of transit cell in each direction, there are two functions for that.

We have proposed that the destination node define the bandwidths for each call dynamically depending on the QoS of each call, and satisfied the equation in which the sum of VPI bandwidths in physical link is fixed at 44 cell/ms.

4-6 Broadband Network Performance

Broadband networks based on ATM cell transfer must meet certain performance requirements in order to be accepted by potential users and network providers. In this section, a brief discussion will be given about ATM layer-specific network performance. However, the quality of service (QoS) as perceived by the user may be influenced not only by the ATM transport network performance but also by higher layer mechanisms. Cells belonging to specified virtual connection are delivered from one point in the network to another. For example, from A to B. A and B may indicated the very endpoints of a virtual connection, or may delimit a certain portion of the cell transport route (for example, A and B may indicate national network boundaries of an international ATM connection). Because there is some transfer delay, cells sent from A arrive at B within $\Delta t > 0$ (see Figure 4-13). Note that the cell exits event occurs when the first bit of the ATM cell has completed transmission across A, and the cell entry event occurs when the last bit of the ATM cell has completed transmission across B. A Discussion about measuring cell delay and cell delay variation or cell jitter is presented in [21].

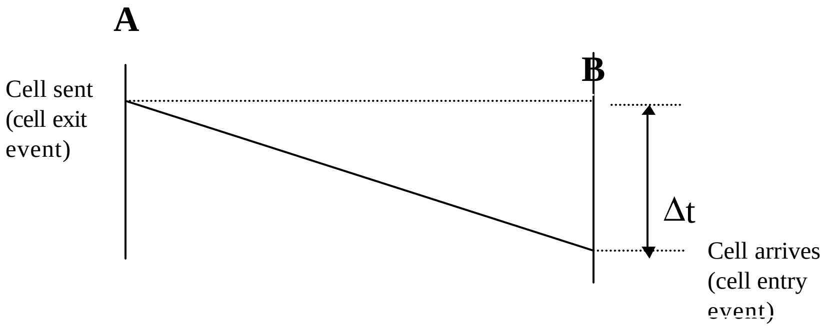


Figure 4-13 Cell Transfer (Schematic)

In order adequately to describe the quality of ATM cell transfer, ITU-T recommendation first defines the following outcome categories:

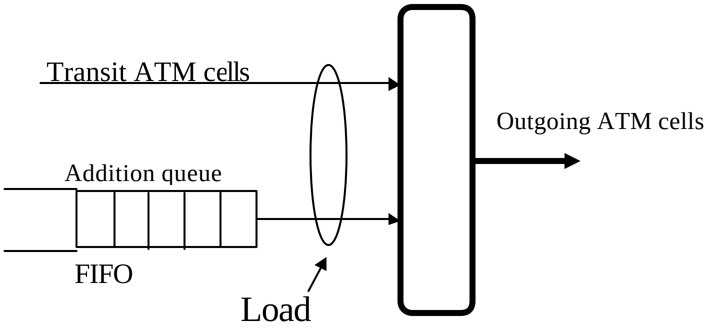
. Successfully transferred cell.
. Errored cell.
. Lost cell.
. Misinserted cell.

If Δt is less than a maximum allowed time T (the exact value is not yet specified) and the cell is not affected by bit errors, then the cell has been successfully transferred. If the cell arrives in due time but there are one or more bit errors in the received cell information field, the cell is errored. A lost cell outcome occurs if the cell arrives after time T (or never reaches B). Errors in the ATM cell header that can not be corrected or cell buffer overflows in the network (for example, in an ATM switch) lead to lost cells. If a cell that has not been sent from A on this virtual connection arrives at B, then this misdelivered cell produces a misinserted cell outcome. Header errors that are not detected or are erroneously corrected may produce misinserted cells. By making use of the above considerations, it is possible to define the performance parameters. The parameters and their definitions are listed in Table 4-1[21].

Parameters	Definition
Cell loss ratio.	Ratio of lost cells to transmitted cells.
Cell misinsertion rate.	Number of misinserted cells per second.
Cell error ratio.	Ratio of errored cells to the number of delivered (Successfully transferred + errored) cells.
Cell transfer delay	Δt .
Mean cell transfer delay	Arithmetic average of a specified number of cells transfer delays.
Cell delay variation.	Difference between a single observation of cell transfer delay and the mean cell transfer delay on the same connection.

Table 4-1 ATM Performance Parameters

There are other parameters such as Throughput (TP) and Offered load (OL). Throughput of a network is defined as the number of cells delivered to their destination station per unit of time. An analysis of throughput, cell loss and delay is discussed in [48]. Offered load (cells/sec) is defined as the number of cells transmitted by all subscribers. Here, the offered load is defined as the ratio of the transit ATM cells plus the added ATM cells to the maximum transmitted ATM cells through the link. So the maximum number of cells can be determined with keeping in mind that the SONET frame has approximately 44 cells. The transmission frame is transmitted in 0.125 ms, the transmitted rate equals to 44/0.125=352 cell/ms. Figure 4-14 depicts the offered load of the ADM/ATM Node.



Outgoing ATM cells = transit ATM cells + added ATM cells.

Load = Outgoing ATM cell per unit of time

Offered load = Load (cells/ms) / 352 (cells/ms).

Figure 4-14 Offered load of ATM/ADM Node

The successful probability of a cell passing through the network is determined by equation (4-3). Thus, the TP is calculated by equation (4-4) by given the arrival rate of the OL.

$$P(\text{cell success}) = 1 - P(\text{cell loss}) \quad \text{----------------------------------} \quad (4\text{-}3)$$

$$TP = OL\,(1 - P(\text{cell loss})) \quad \text{----------------------------------} \quad (4\text{-}4)$$

Dividing the throughput (TP) by the effective input load (OL), gives probability of the success cell which also represent the node utilization by the following equations (4-5), and (4-6).

$$\mathbf{U = P(cell\ success) = TP/\ OL} \quad \text{--------------------------------} \quad \mathbf{(4\text{-}5)}$$

$$\mathbf{P(cell\ loss) = 1 - (TP/\ OL)} \quad \text{--------------------------------} \quad \mathbf{(4\text{-}6)}$$

Usually most arriving cells wait in the queue for at least one time slot. However, under a light load of traffic, more cells can be delivered directly through the network upon their arrivals. An end-station queuing model is shown in figure 4-15. The total cell delay consists of three components: queuing time, access time and transmission time [49].

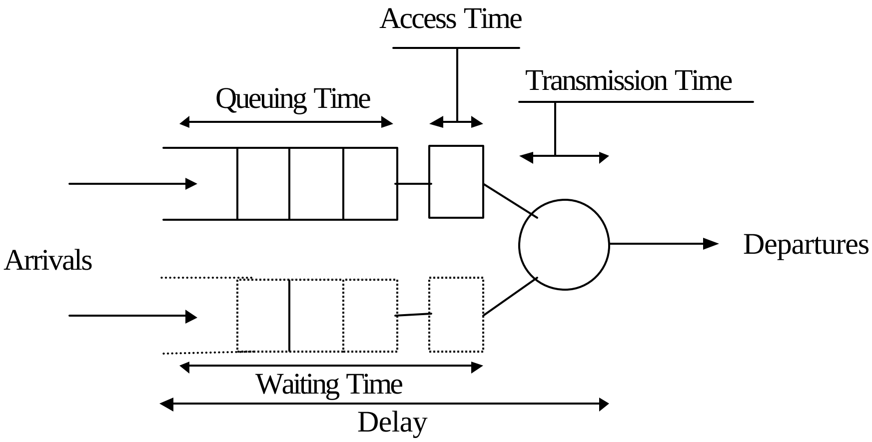


Figure 4-15 End-Station Delay Model

The queuing time is the time a cell spends in the queue, (i.e. from the time it arrives to the queue to the time it reaches to the head of the queue. The access time is the time elapsed from the moment a cell reaches the head of the queue to the time a transmission frame is captured for its transmission. The transmission time is the time needed to transmit a cell.

4- 7 Simulation Check Point

In this section a simulation checkpoint is presented. It is the classic example and the analytical techniques required rather elementary. Whereas these techniques do not carry over into more complex queuing system, the behavior of queue model is in many ways similar to that observed in the more complex cases.

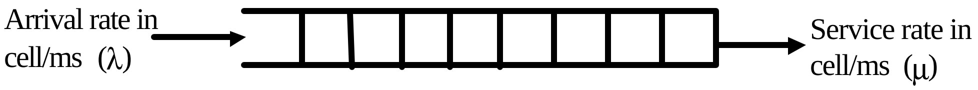


Figure 4-16 The Queue model

The queue model is defined by many parameters such as arrival rate (l), service rate (m), traffic intensity (r), Mean Waiting Time (MWT), and Average queue size (B_{siz}). Figure 4-16 describes the queue model, which can be represented by the following equations [50].

$$r = \frac{l}{m} \tag{4-6}$$

$$\mathbf{MWT} = \frac{1}{m}\left(\frac{1}{1-r}\right) \tag{4-7}$$

$$\mathbf{B}_{siz} = (\mathbf{MWT})\ l \tag{4-8}$$

A comparison between the results of the simulation and the analytical can be shown in Figure 4-17.

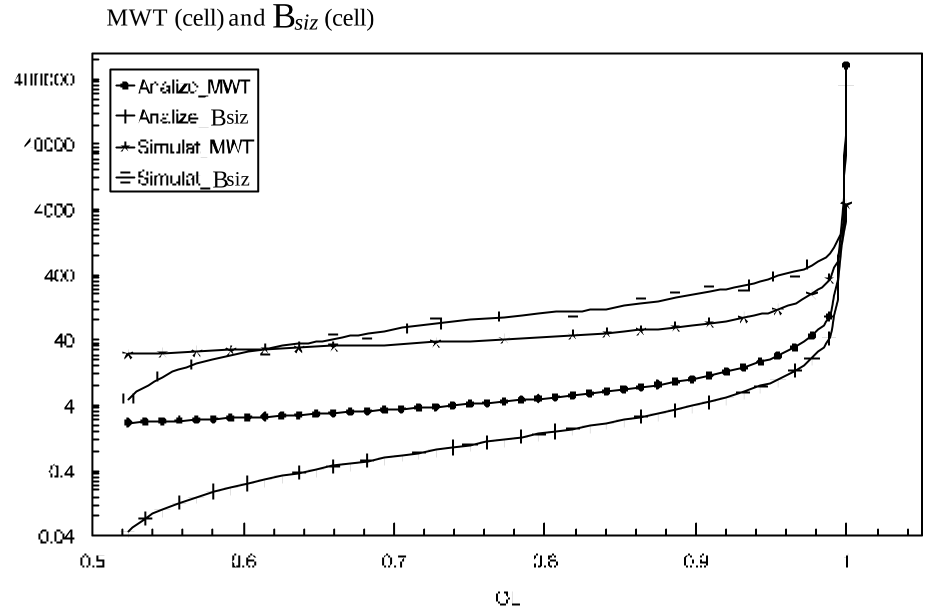


Figure 4-17 Comparison between Analytical and Simulation Results

Figure 4-17 illustrates the MWT and B_{siz} versus OL, it is very clear that the behavior of both analytical and simulation results is almost similar. However, as the OL increases, the MWT and B_{siz} slightly increasing up to saturation limit. Beyond the saturation limit, MWT and B_{siz} sharply increase, this is due to the huge number of cells which increases the MWT and MBS. Also cearly that at a certain OL, MWT and B_{siz} in the case of simulation results are more than MWT and B_{siz} in the case of analytical results. That is because the system serve the coming cells by rate of 352 cell/ms for time interval 0.0625 ms and wait with no serve the coming cells in next time interval of 0.0625 ms. To make the simulation model closed to the analytical model, we have to considered the service time as effective service time (0.0625 ms) as shown in the Figure 4-18.

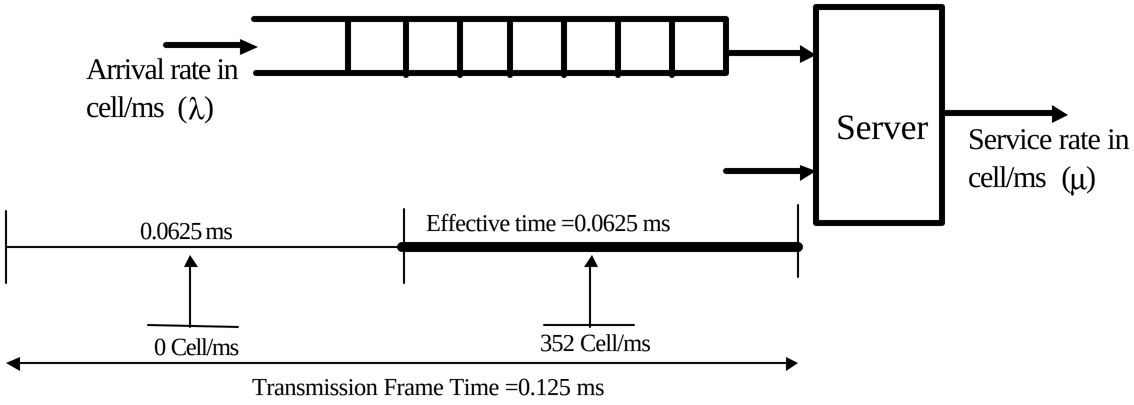


Figure 4-18 Simulation Queue Model

In the simulation model, the server picks up cells from the queue by rate equal to 352 cell/ms through the time interval of 0.0625 ms, then no service for the cell within the next interval of 0.0625 ms, and so on. Another results of the simulation and analytical have been compared using equation used in Figure 4-19. The simulation and analytical results have the same characteristic behavior as shown in Figure 4-19, the increasing of OL, increases MWT and B_{siz} up to saturation limit. Beyond the saturation limit, MWT and B_{siz} rapidly increase because the increasing of OL after the saturation limit increases the number of cells resulting in long queue and MWT. From the Figure, it is also obviously that at a certain OL, MWT of simulation and analytical models are closed to each other and B_{siz} of simulation and analytical models are closed to each other. By the way, the analytical results are approximation results and the purpose of the analytical model to confirm that the proposed simulation is working properly.

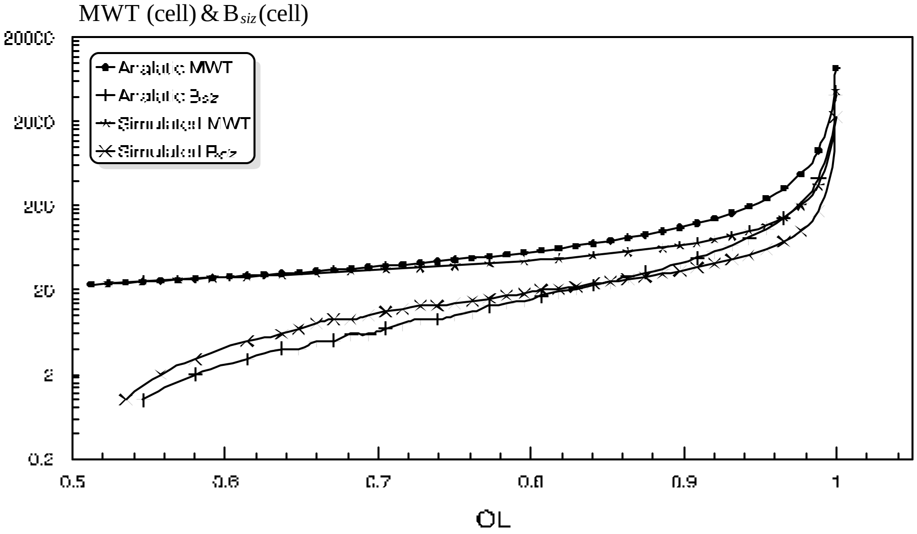


Figure 4-19 Comparison between Simulation and Analytical Results