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HDFS Write Operation Using Fully Connected Digraph DataNode Network Topology

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Abstract

Hadoop is an open source implementation of the MapReduce Framework in the realm of distributed processing. A Hadoop cluster is having the capability to handle large amounts of data. To handle massive scale data, Hadoop exploits the Hadoop Distributed File System termed as HDFS. Client will write data to DataNodes by taking the blocks info from NameNode . The DataNodes containing the blocks will be connected in pipeline fashion. While writing the data if DataNode /network fails the failed DataNode will be removed from the pipeline. Based on the available DataNodes in the cluster the new DataNode will be included in the pipeline. If there are very less number of spare nodes in the cluster users may experience an unusually high rate of pipeline failures since it is impossible to find new DataNodes for replacement. If network failure happend ,the data packet cannot be reached to the target DataNode since they are connected in pipeline fashion. If each DataNode is connected to each other DataNode then there will not be any issue with network failure since they have number of paths through other DataNodes. In pipeline connectivity the copy operation will take longertime , where as in DataNode is having direct connection to all other DataNodes , it will take very less time because datapacket is not required to traverse through all other DataNodes to reach the end DataNode . In this paper we will address the network failure issues among the DataNodes and reducing the copy operation time to copy data packet to DataNodes which are in pipeline by fully connected digraph network topology. Using this topology network complexity will be high, but we can reduce the time to copy one data packet to all replica locations (DataNodes) and nullify the network failure issues among the DataNodes.

Keywords: Hadoop Distributed File System (HDFS), NameNode , DataNode, Replica, Rackawareness, Data Packet, Data Packet Transfer Time, Pipeline, Fully Connected Digrapgh Network Topology.

INTRODUCTION

Hadoop Distributed File System (HDFS)[1] is a distributed file system that is developed to deploy on low cost commodity hardware to store very large datasets reliably and has high degree of fault tolerance and also stream those data sets at high bandwidth for user applications to run on commodity hardware. It is a master/slave architecture where master is called NameNode and slaves are called DataNodes. HDFS has many similarities with existing distributed file system, but they are very different. A distributed file system consists of single NameNode and multiple data nodes and provides availability and reliability by holding multiple replicas of data. NameNode and Datanode interactions are high while reading or writing to file when there is a heavy work load which will decrease the performance. The system having the NameNode acts as the master server. NameNode maintains the metadata pertaining to the file system, such as the file hierarchy and the block locations for each file. It also performs file system operations such as closing, opening and renaming files and directories. Each storage node runs a process called a Datanode that manages the blocks on that host, and these are controlled by a master NameNode process running on a separate host. To meet exponential storage demands of Hadoop[1], MapReduce[5], Dryad[10] and HPCC(High-Performance Computing Cluster)[12] frameworks disk based file systems is the suitable file system.A requested task can be completed efficiently, when the computation takes place near the data. In case of huge datasets are involved, operation reduces the network traffic and increases the throughput. Hadoop distributed file system (HDFS) [6] has the potential to

store huge amounts of data since it is having huge number of nodes in each cluster. Need to pay some time penalty while retrieving or keeping the data in DataNode . There are different components to reduce disk access latencies like scheduling jobs on same node that consists of associated data, in addition, information is copied to different nodes in number ways to improve the performance in job completion time. A fully connected network is a communication network in which each of the nodes is connected to each other. In graph theory it is known as a complete graph. There will be number of alternative paths from one DataNode to each other DataNode in the cluster which includes only replication factor number of DataNodes in the connection process. So we can use the number of alternative paths from one DataNode to other DataNode incase of any failure in the existing path between two DataNodes. Even copy operation also will take less time since we can apply parallel copy process among the datnodes from the starting DataNode which is connected directly from the client to all other DataNodes which are part of the replication factor.The new features of the proposed method are reducing the copy operation time among the DataNodes and providing the number of alternative paths to reach the target DataNode in case of network failure.In the existing process we are configuring the parameters dfs.client.block.write.replace-datanode-on-failure.enable,dfs.client.block.write.replace-datanode-on-failure.policy. Once we start using the proposed architecture we no need to change the DataNodes in case of network failure , instead of that we can reach the DataNode using alternative paths among the DataNodes. This paper describes the concepts such as literature survey on the existing mechanism using for HDFS memory operation, description of HDFS components , the problem in the existing architecture , proposed architecture using fully connected digraph DataNode network topology , the implementation and the evaluation process using the simulation results . This paper presents the mechanism to reduce the copy operation time to DataNodes (replication of datapackets) and to nullify the network failure issues among the DataNodes by using fully connected digraph network topology[4].

LITERATURE REVIEW

HDFS with Linear DataNode Connectivity

HDFS system is implemented on Linux machine. When a client makes a request for reading some HDFS data, it first contacts the NameNode to find out the first few blocks of the file it wants to read. The NameNode returns the addresses of all DataNodes that store a copy of those first few blocks, ranking the DataNodes in order of their closeness to the client. The client then reads the data from the DataNodes in the preferential order presented to it. Should the first DataNode fail during the read say because the DataNode is dead , the client automatically connects to the next DataNode in the list and reads the block. When the client reads the block, it also verifies that the blocks current checksum is the same as the original checksum calculated when the block was first stored on disk. If the checksum differs, again the client will move to a different DataNode in the list to read the data. The client also informs the NameNode that it found a potentially corrupt block and the NameNode will replicate the corrupt block to another DataNode. A DataNode will verify checksums for all blocks it stores every three weeks. If the read request emanated from one of the clusters DataNodes, the first choice of the client would be to see if that DataNode itself can satisfy the read request, without having to go to a non-local DataNode. As the client starts reading through the first few blocks, it requests that the NameNode send it the locations for the next set of data blocks. The NameNode will send the best list of DataNodes for each data block. In Client write operation the client will create the file and connect to the NameNode for that namespace. The NameNode after verifying that the file doesn't already exist and the client has sufficient permissions to create the file, records the new file in its metadata and sends the block name and list of DataNodes to the client. The list of DataNodes is called a pipeline. The pipeline specifies the DataNodes on which the clients can place the block replicas. The file the client wants to write out to HDFS is split into blocks and these blocks are stored on HDFS on various DataNodes. The client connects to the first DataNode in the pipeline and starts writing the data blocks on that node. the first DataNode will connect to the second DataNode in the list and forward it the data blocks as it receives them. The second DataNode inturn connects to and forwards the data to the next DataNode in the pipeline. When all three (by default) replicas are completely written to the client, an acknowledgement packet is relayed through the pipeline of DataNode to the client, to indicate that the block was successfully written to all nodes. The client willstart writing the next block at this point.When all block replicas are written, the block is committed in the edit log by the NameNode and marked as "written." When the client completes writing data to the file, it closes the file. This requires that all the file's blocks have been replicated the minimum number of times. The client may have to wait to close the file if there are any DataNode failures in the process. The client informs the NameNode that the file writing was successfully completed. The writing of the block replicas is done asynchronously. The client doesn't have to send the data blocks it's writing to all the DataNodes. It just sends them to one of the DataNodes in the list provided by the NameNode , and it's the responsibility of that DataNode to send the data blocks along to the other DataNodes in the pipeline. Each DataNode will also save a checksum of each data block it stores. When this block is read , its checksum is verified to ensure that the block is complete and isn't corrupt. The NameNode creates metadata from the block reports it receives from the DataNodes. HDFS stores the data blocks such that the availability of one or more nodes won't cause a

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data loss. Hadoop automatically replicates any lost blocks. Data replication ensures both availability and data locality, which helps enforce a guiding principle of Hadoop, which is to bring processing to the data and not the other way round, as it is in traditional database systems. The existing system is using dfs.client.block.write.replace-datanode-on-failure.enable,dfs.client.block.write.replace-datanode-on-failure.policy parameters to maintain the fault tolerance even when the DataNode /network failure while writing or reading data from DataNodes. DFSClientwill request for data blocks from the NameNode . Once the client gets the list of data blocks , client will open the Out stream for write operation. Data will be written to nearest DataNode (block) , and this DataNode will be connected to other DataNodes (number of DataNodes based on the replication factor) in pipeline fashion[7-8]. If there is a DataNode /network failure issue in the write operation (pipeline), DFSClient will remove the failed DataNode from the pipeline and then resume write operation with the remaining DataNodes. As a result of this operation, the number of DataNodes in the pipeline will go down. The feature is to add new DataNodes to the pipeline. When the number of nodes in the cluster is (cluster size) extremely small, example number of nodes is 3 or less, cluster administrators may want to set the policydfs.client.block.write.replace-datanode-on-failure.enable to NEVER in the default configuration file (hdfs-default.xml) or disable this feature. Otherwise, users may face an unusually high rate of pipeline failures since it is impossible to find new DataNodes for replacement. If we have four nodes and a replication factor of 3, each block will have a replica on three of the live nodes in the cluster. If a node dies, the blocks living on the other nodes are unaffected, but any blocks with a replica on the dead node will need a new replica created. However, with only three live nodes, each node will hold a replica of every block. If a second node fails, the situation will result into under-replicated blocks and Hadoop does not have anywhere to put the additional replicas. Since both remaining nodes already hold a replica of each block, their storage utilization does not increase. DataNodes will be connected (based on the blocks from the Namespace) using pipeline. In the existing architecture to deliver the packet it needs to traverse through all the DataNodes to reach the last DataNode (based on the replication factor we need to decide last number).Refer with: Fig. 1, While writing the data if DataNode /network fails the failed DataNode will be removed from the pipeline. Adding the new DataNode to pipeline will depend on the available nodes in the cluster. The problem in the existing architecture is users may experience an unusually high rate of pipeline failures since it is impossible to find new DataNodes for replacement. The time required to send the data packet and getting the acknowledgement back to source DataNode will take longer time since the DataNodes are connected in linear pipeline fashion.

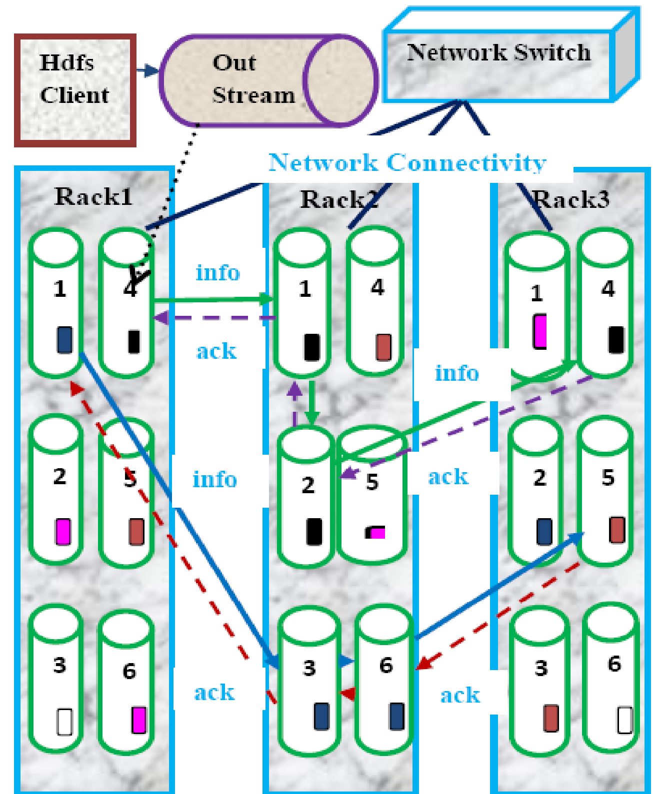


Figure 1: DataNode pipeline connectivity.

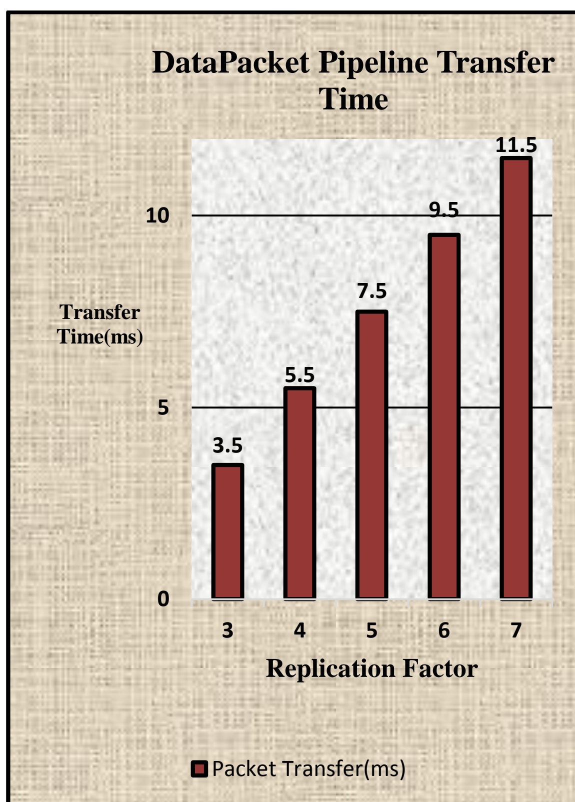
If we consider one millisecond is for inter rack DataNode packet transfer and 0.75 millisecond is for intra rack DataNode packet transfer, then (replication factor is 4, DataNode2 and DataNode3 are in second rack, where as DataNode1 and DataNode4 are in rack1 and rack4 respectively) 1 millisecond to reach to second DataNode , 0.75 to reach from DataNode2 to DataNode3 and 1 millisecond from DataNode3 to DataNode4. So the total time is 1+0.75+1 = 2.75 milliseconds. The same is applicable for acknowledgement transfer as well.So total 5.50 milliseconds required to complete one packet copy operation with replication factor 4. Referwith: Table 1for the time taken for copy operation of one packet using different replication factors.

Table 1: Packet Transfer time with different replicationfactors

Replication Factor	Packet Transfer(ms)
3	3.5
4	5.5
5	7.5
6	9.5
7	11.5

The time is growing up while increasing the replication factor, because the DataNodes will be connected in pipeline fashion[3] (one DataNode to another till the last DataNode and the number of DataNodes in the pipeline depends on the replication factor). For files which are frequently accessed or critical, setting the replication factor improves their tolerance against faults and increases the read bandwidth. In the existing system we are using the parameter dfs.client.block.write.replace-datanode-on-failure.enable[3] to replace the DataNode in case of DataNode /network failure. If the number of spare nodes are less or unavailable , then we need to set the parameter to NEVER so that we can externally informing to file system that , there will not be any node replacement in case of any network/node failure. This is having the limitation on number of DataNodes available in the cluster. Refer with: Graph 1 for the time status while increasing the replication factor.

Graph 1: ReplicationFactor Vs PacketTransfer time



NameNode

NameNode is the centrepiece of Hadoop Distributed File System. NameNode is also known as the Master. NameNode only stores the metadata of HDFS – such as the file hierarchy and the block locations for each file. NameNode does not store the actual data or the dataset where as the data will be stored in DataNodes. NameNode is usually configured with a lot of memory (RAM). NameNode knows the list of the blocks and its location for any given file in HDFS. It is easy for NameNode to construct the file from blocks since it is having knowledge on blocks and locations. NameNode is having namespace consists of files and directories . Inodes will be used here to represent the files and directories. Inode is having the file permissions , modification and access time , disk space and namespace info.The file content is devided into blocks (typically 128MB) each block of file is independently replicated at multiple DataNodes. NameNode is having the info related to mapping of file blocks to DataNodes. When a client makes a request for reading some HDFS data, it first contacts the NameNode to findout the locations of the first few blocks of file it wants to read. Whereas in write operation the set of DataNodes to host the block replicas will be allotted by NameNode to client upon the request from the client. In the next phase the write operation to DataNodes in pipeline fashion[7-8] will be performed by client . The file the client wants to write out to HDFS is split into blocks and these blocks are stored on HDFS on various DataNodes. The client connects to the first DataNode in the pipeline and starts writing the data blocks on that node.

DataNode

In a Hadoop cluster, which consists of multiple nodes, one or more of the nodes will act as a master nodes[13]. The master nodes run key Hadoop services such as the NameNode and the Resource manager. The rest of the servers in a Hadoop cluster are worker nodes, commonly referred to as DataNodes. It's these nodes that actually store the data blocks. The DataNode performs the functions (based on the directives sent by the NameNode) like providing the block storage by storing blocks on the local file system, fulfilling the read/write requests from the clients who want to work with the data stored on the DataNodes, creating and deleting datablocks, replicating data across the cluster, keeping in touch with NameNode by sending periodic block reports and heartbeats. A heartbeat confirms the DataNode is alive and healthy ,and a block report shows the blocks being managed by the DataNode. The file in a file system will be partitioned into one or more segments and/or stored in individual data nodes. These are called as blocks. The default block size is 128MB, but it can be increased using HDFS configuration. NameNode will be having handshake at startup with all DataNodes. In the handshaking process the namespace ID and software version of DataNode will be verified. In the successful case of matching, the communication will start with DataNode . In the case of mismatch DataNode will automatically shuts down. DataNodes are not connected directly to the NameNode but communicate with them as the need occurs. When the DataNode is started (or restarted), it registers with the NameNode to let it know that it's available to handle HDFS read and write operations.A recently initiated DataNode with no namespace ID can join the cluster and it will get the group's (cluster) namespace ID. Each DataNode persistently saves its unique storage ID, which help to recognize the DataNode after restarting it with different port

or IP address. All DataNodes periodically(every three seconds by default) send a heartbeat containing statistical usage information for that DataNode to the NameNode . This heartbeat lets the NameNode that it can send commands such as block replication or deletion to the DataNodes. If the NameNode does not receive a heartbeat for a long time, it requests an immediate block report from the DataNode. If the NameNode does not recognize the DataNode, either because the NameNode has restarted , or because the network connection with the DataNode has timed out, it asks the DataNode to register again.

If a DataNode fails to send its periodic heartbeat even after a long time (such as ten minutes), the NameNode will mark that DataNode as dead and issues commands to other DataNodes to replicate the data stored on the dead DataNode, to makeup the replication factor of the blocks to the configured number of replicas. NameNode sends instructions to DataNodes as acknowledgement to heartbeat. Refer with:Fig.2 for HDFS Architecture.

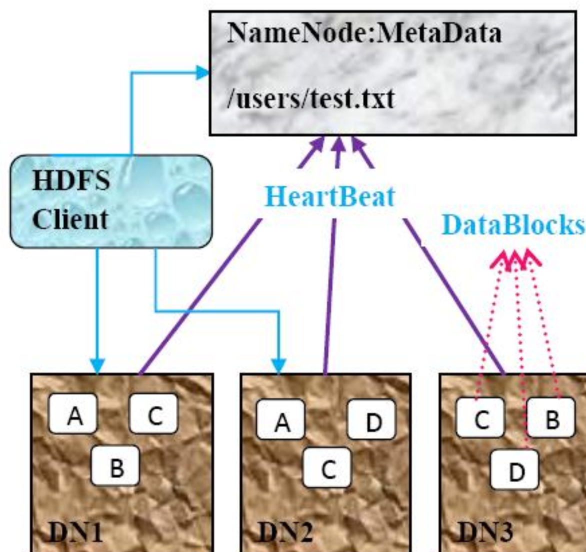


Figure 2: HDFS Write Operation

Rackawareness

Hadoop components are rack-aware. Usually Hadoop clusters of more than 30 to 40 nodes are configured in multiple racks. Communication between two DataNodes on the same rack is efficient than the same between two nodes on the separate racks. In large clusters of Hadoop, in order to improve network traffic while reading or writing HDFS, NameNode chooses DataNodes which are on the same rack or nearby rack to read or write request. NameNode achieves this rack information by maintaining rack ids of each DataNode . This concept of choosing DataNodes based on racks information is called Rack awareness in Hadoop. Replica placement via Rackawareness is a simple policy [2] to place replicas across racks.This stops loosing data when an entire rack fails and allows to make use of bandwith from multiple racks while reading a file. On multiple rack cluster, block replications are maintained with a policy that no more than one replica is placed on one DataNode and no more than two replicas are placed in the same rack with a constraint that number of racks used for block replication should be always less than total number of replicas.

When a new block is created, the first replica is placed on the local DataNode, the second one is placed at a different rack , the third one is on a different DataNode at the local rack. When re-replicating a block, if there is only one replica, place the second one on a different rack. When the number of existing replicas are two, if the two replicas are on the same rack , place the third one on a separate rack. For reading, the NameNode first checks if the clients computer is located on the cluster. If yes, block locations are returned from the closed DataNodes to the client. This policy minimizes the write cost while maximizing the read speed. This provides data availability in the event of a network switch failure or partition within the cluster.

HDFS Write Operation

An HDFS cluster is comprised of a NameNode and one or more DataNodes. In this section, we have given a comprehensive analysis about how a client communicates with the NameNode and DataNodes when uploading data to HDFS[7-11].

File creation into the file system's namespace:

The client first makes a create() HDFS call, which results in a ClientProtocol RPC being invoked to create a new file on the NameNode . Before the creation of the file in the namespace, the NameNode conducts several checks, e.g., whether the file already exists, whether the user has the right to create the file, and whether safe mode is disabled. If all these checks pass, the NameNode would create the corresponding file in the file system's namespace; otherwise it would throw an exception.

Packets forming from data and inserting into a data queue:

To write data to HDFS, client applications consider the data file as a standard output stream. This data stream is fragmented into blocks, each of which has a default size of 64MB. In turn, each block is split into 64KB packets by default when being transmitted onto the network. When the client writes a new block, a DataStreamer thread would send an addBlock() call to the NameNode to ask for a new block ID and the DataNode IDs to store the block. After the corresponding packets are generated, the client sends these packets to a FIFO queue and then to the DataNodes.

Packets to DataNodes:

DataStreamer uses the DataNode IDs to build a pipeline

between the client and these DataNodes, streams the packets to the first DataNode in the pipeline one by one, and stores these packets into another queue called ACK queue in case some DataNodes require retransmitting due to packet loss. When the first DataNode receives a packet, it verifies the packet's checksum, stores the packet, and transfers it to the next DataNode in the pipeline. This procedure will repeat until the packet reaches the last DataNode at the end of the pipeline.

Sending acknowledgement (ACK) to the client:

When the last DataNode obtains the packet, it would send an ACK through the pipeline in a reverse order. The client has a thread called PacketResponder that is responsible for receiving response ACKs. If the PacketResponder thread receives a packet ACK from all DataNodes, it removes this packet from the ACK queue.

Close the output stream:

When the client has flushed all data into the output stream, it calls close() on the stream, and waits for all packets' ACKs.

Completing file write:

When all packets' ACKs are received by the PacketResponder thread, it wakes up the client. The client would send a complete signal to the NameNode to complete this file write operation. Refer with: Fig.3 for HDFS write operation.

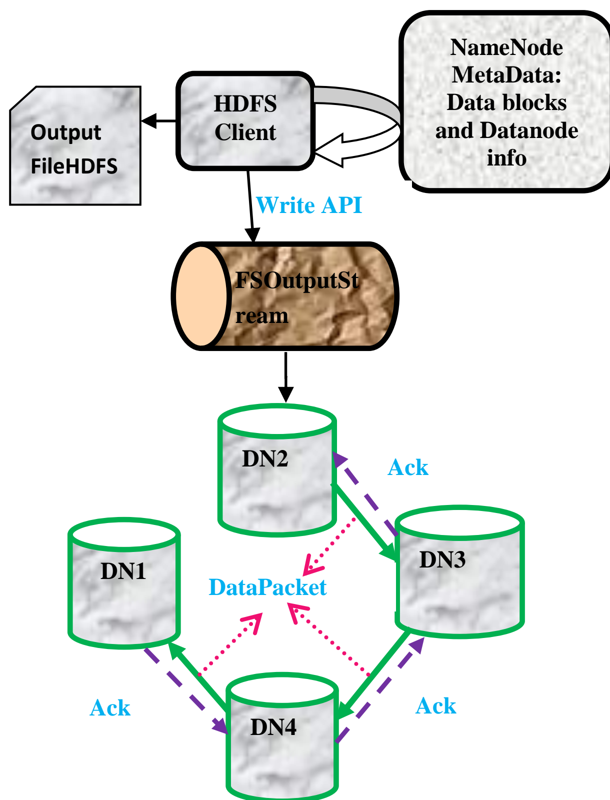


Figure 3: HDFS Write Operation

As per the namespace DN1,DN2,DN3 and DN4 are connected in a pipeline fashion. Once the packet has been written to DN2 by FSDataOutputStream, then it will be transferred to DN3 by DN2 , DN3 to DN4 and DN4 to DN1. Acknowledgement will be transferred back from DN1 to DN4 , DN4 to DN3, DN3 to DN2.The solid lines from DN2 ->DN3->DN4->DN1 in the figure is showing data packet transfer and dotted lines from DN1->DN4->DN3->DN2 is showing acknowledgement. Using the configuration (hdfs-site.xml) we can set the replication factor of a file. By default the replication factor is three. Here we are taking the replication factor as four. DN1 is in rack1, DN2 and DN3 are in rack2 and DN4 is in rack3. As discussed assume that one millisecond is for inter rack DataNode packet transfer and 0.75 millisecond is for intra rack DataNode packet transfer, then (replication factor is 4, DataNode2 and DataNode3 are in second rack, where as DataNode1 and DataNode4 are in rack1 and rack4 respectively) 1 millisecond to reach to second DataNode , 0.75 to reach from DataNode2 to DataNode3 and 1 millisecond from DataNode3 to DataNode4. So the total time is 1+0.75+1 = 2.75 milliseconds. The same is applicable for acknowledgement transfer as well. So total 5.50 milliseconds required to complete one packet copy operation with replication factor 4. We can reduce this time using fully connected network topology among the DataNodes.

PROPOSAL METHOD

Problem Statement

DataNodes are connected (based on the blocks from the Namespace) using pipeline. While writing the data if DataNode /network fails, the failed DataNode will be removed from the pipeline. Based on the available DataNodes in the cluster the new DataNode will be included in the pipeline. If there are very less number of spare nodes in the cluster users may experience an unusually high rate of pipeline failures since it is impossible to find new DataNodes for replacement. If network failure happend , the data packet cannot be reached to the target DataNode since they are connected in pipeline fashion. In pipeline connectivity the copy operation will take longer time ,since it needs to traverse through all the DataNodes connected in pipeline till the last DataNode . The problem in the existing architecture is users may experience an unusually high rate of pipeline failures since it is impossible to find new DataNodes for replacement and the copy operation is taking longer time since the DataNodes are connected in pipeline fashion.

Proposal

We can connect the DataNodes using fully connected digraph network topology[4] , where each DataNode is connected to every other DataNode as per the list from the NameNode .

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We can have number of alternative paths in case of network failure in the current part and we can improvethe write operation performance by decreasing the operation time using the new architecture. DFSClient will request for data blocks from the NameNode . Once the client gets the list of data blocks , client will open the Out stream for write operation. Data will be written to nearest DataNode (block) , and this DataNode will be connected to other DataNodes (number of DataNodes based on the replication factor) in pipeline fashion. If there is a network failure in the write pipeline, the operation cannot be completed . To avoid this connectivity issues , we can use the DataNodes using fully connected digraph network topology[4] , where each DataNode is connected to every other DataNode as per the list from the NameNode . Total number of edges are n(n-1) if there are n DataNodes in the pipeline. Each DataNode is having n-1 outgoing edges to connect to n-1 DataNodes.The existing architecture each DataNode is having 2(n-1) edges where as n-1 edges for datapacket copy operation and the other n-1 for acknowledgement. Solid lines are datapacket transfer operation and dotted lines for acknowledgement operation. Here the dotted lines mentioned with double direction.

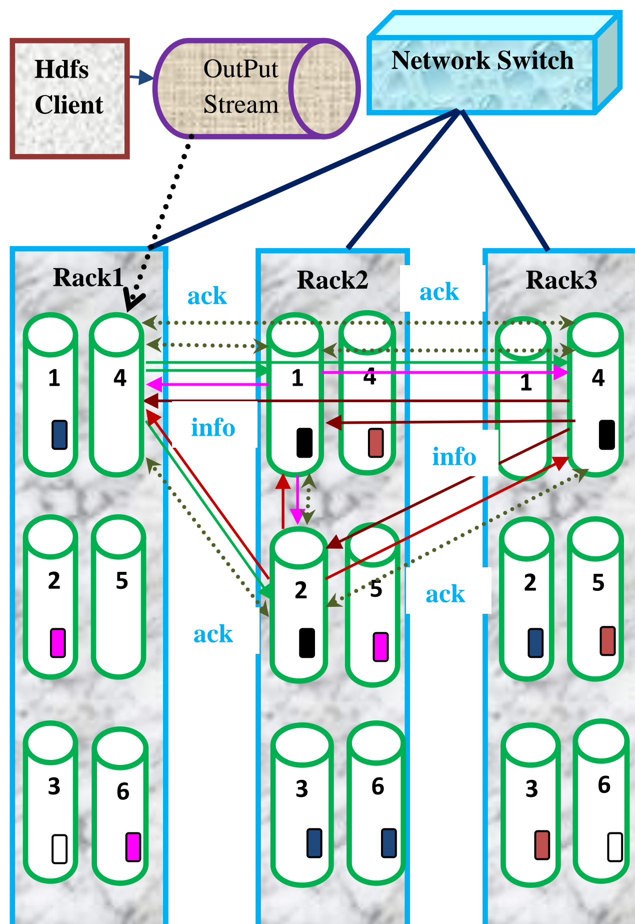

Figure 4: DataNodes with fully connected digraph network topology

Refer with: Fig 4. for proposed architecture. Replication factor is the number of copies the data block will be copied in cluster. The replication factor 4 has been used here, so the data is available in four DataNodes. The cluster is having three racks Rack1, Rack2 and Rack3 and each rack is having 6 DataNodes. DN1, DN2, DN3, DN4, DN5 and DN6 are represented as 1, 2, 3, 4, 5 and 6 respectively. The representation is same for each rack. As shown in the figure the data packet (using distinct colors to distinguish data packets) is stored into DN4 in Rack1 , DN1 and DN2 in Rack2 followed by DN4 in Rack3(Replicationfactor is 4). Here single direction lines are for datapacket transfer operation and bidirectional dotted lines for acknowledgement operation. DataNode DN4 in Rack1 is connected to three DataNodes DN1(Rack2),DN2(Rack2) and DN4(Rack3). Once the client writes data packet to DataNode DN4 in Rack1 this will get copied to all other DataNodes in the list DN1 in Rack2, DN2 in Rack2 and DN4 in Rack3 simultaneously. The acknowledgement packet will be transferred back to DN4 in Rack1 from all other DataNodes simultaneously. Since this is parallel operation both in forward (sending packet) and backward (acknowledgement) direction , the time required to complete one packet copy operation is just twice the time required for inter rack packet copy operation , and if there is intra rack DataNode is available in the replication list then the total time will be lesser than the time which we have counted in inter rack packet transfer. If there is any network failure while copy operation is in progress we can reach the destination DataNode using number of alternative paths, i.e,if the replication factor is 3 we can have one alternate path, if it is 4 we can have 4 alternative paths , for 5there will be 15 alternate paths and for replication factor 6 we can have 40 alternate paths. The complexity of network implementation[9] is high compared to existing architecture but we can nullify the network issues and we can decrease the time required to write the datapacket.

In the existing system we are using the parameter dfs.client.block.write.replace-datanode-on-failure.enable [3] to replace the DataNode in case of DataNode /network failure. We need to set this parameter to NEVER in case of cluster size is very small like having three DataNodes. If the number of DataNodes are three then in case of network failure there will be any choice to replace , instead of that we need to face the consequences of failure. Need to set as true in case of having more number of nodes in the cluster so that we can replace with new DataNode . In the proposed architecture in case of network failure we no need to depend on the replacement of the DataNode with new DataNode , instead of that we can reach the target DataNode using the shortest path from the remaining paths.We can find the shortest path from single source DataNode to all other DataNodes using Dijkstras shortest path algorithm[9]. Consider replication factor is the number of vertices V and E the number of edges then the total complexity to get the shortest path to all

DataNodes from single source is O(E Log V) and there will be number of unused paths in each copy operation , these are the two extra complexities which we need to face to nullify the network failure issues. Please find the pseudo code for Dijkstra's Algorithm.

Foreach node set distance[node]=HIGH

TraversedNodes=empty

UnTraversedNodes=empty

AddstartNodetoUnTraversedNodes

distance[startNode]=0

while(UnTraversedNodes is not empty){

assessmentNode=findShortDistanceNode(UnTraversedNodes)

remove assessmentNode fromUnTraversedNodes

add assessmentNode to TraversedNodes

assessedNeighbours(assessmentNode)

}

findShortDistanceNode(UnTraversedNodes){

find the node with the minimum distance in

UnTraversedNodes and return it.

}

assessedNeighbours(assessmentNode){

For Each target node which can be reached via

and edge from assessmentNode

AND which is not in TraversedNodes{

edgeDistance=getDistance(edge(assessmentNode, targetNode)){

newDistance=distance[assessmentNode]+edgeDistance

if(distance[targetNode] >newDistance){

distance[targetNode] = newDistance

add targetNode to UnTraversedNodes}}}}

Dijkstra algorithm partitions all nodes into two distinct sets: untraversedNodes and traversedNodes. Initially all nodes are in the untraversedNodessets, e.g. they must be still evaluated. A node is moved to the traversedNodesset if a shortest path from the source to this node has been found. Initially thedistance of each node to the source is set to a very high value. First only the source is in the set of untraversedNodes. The algorithms runs until the unsettledNodesnumber becomes zero. In each iteration it selects the node with the lowest distance from the source out of the untraversedNodes. It reads all edges which are outgoing from the source and evaluates for each destination node, using the edges which are not yet settled, if the distance which is already calculated from the source to this node can be reduced while using the selected edge. If this is going to happen then the distance is updated and the node is added to the nodes which need evaluation. This is how can have number of alternative paths so that users will escape from experiencing an unusually high rate of pipeline failures.

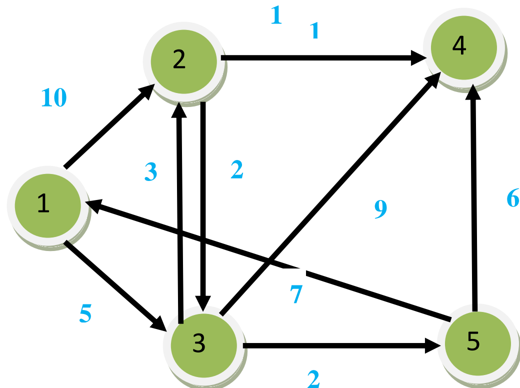

Figure 5: Input Graph

Here I am considering the weights as real numbers just to explain the Dijkstras algorithm instead of taking one millisecond and 0.75 millisecond. Please Refer with: Fig 5.

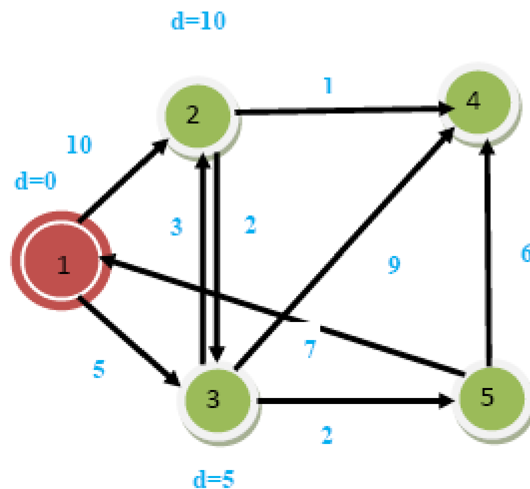

Figure 6: Input Graph

Node being considered: 1

Nodes Not yet finalized: {2,3,4,5}

Distances={INF,INF,INF,INF,INF}

Please Refer with: Fig 6. In this we are considering node 1. The remaining we are not considering. So the distances are INFINITE.

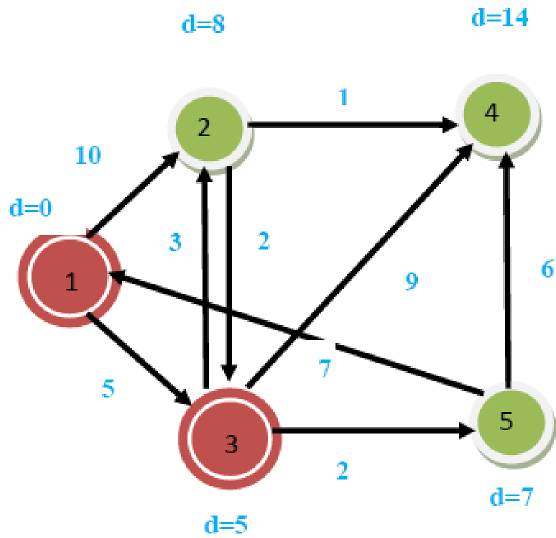

Figure 7: Input Graph

Node being considered:3

Nodes Not yet finalized: {2,4,5}

Distances={0,10,4,INF,INF

Please Refer with: Fig 7. Here considering node 3 after 1.We will we take the minimum i.e, 3 and proceed.

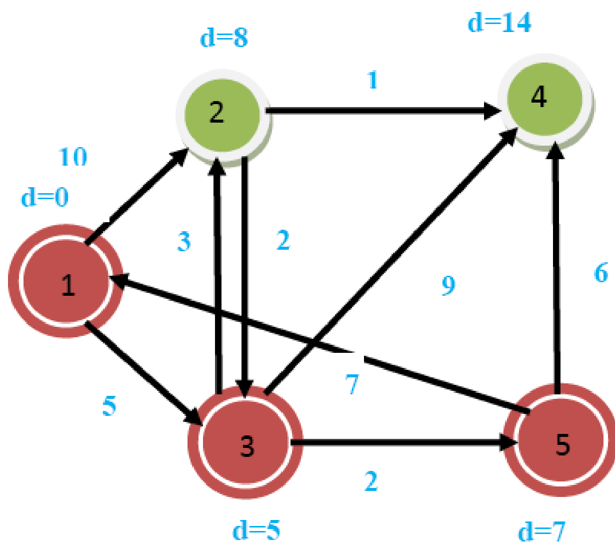

Figure 8: Input Graph

Please Refer with: Fig 8 for the status of nodes and distances while considering node 5. Nodes Not yet finalized: {2,4}

Distances={0,8,5,14,7}

Distance[2]=Distance[3]+wt(3,2)=8

Distance[4]=Distance[3]+wt(3,4)=14

Distance[5]=Distance[3]+wt(3,5)=7

we will consider minimum node i.e, 5 and proceed.

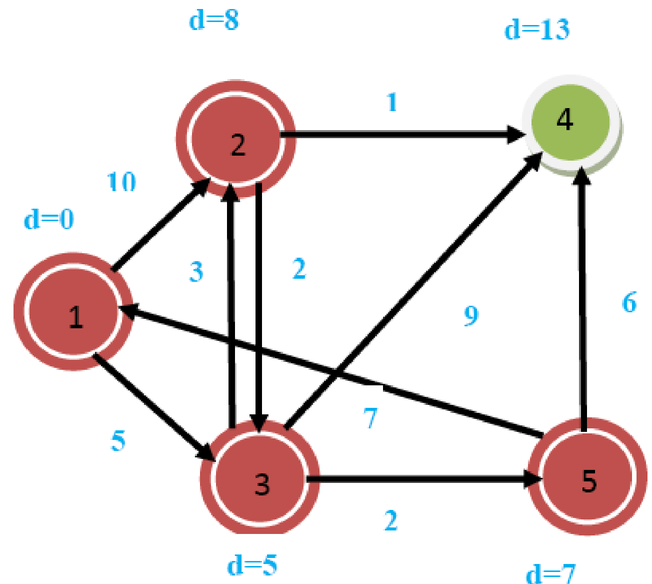

Figure.9: Input Graph

Please Refer with: Fig 9 for the status of nodes and distances while considering node 2.

Nodes Not yet finalized: {2,4}

Distances={0,8,5,13,7}

Distnace[4]=Distance[5]+wt(5,4)=13

we will consider minimum node i.e, 2 and proceed.

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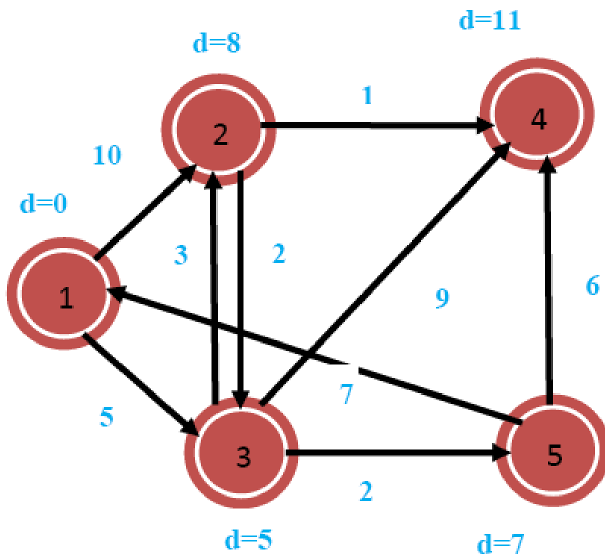


Figure 10: Input Graph

Please Refer with: Fig 10 for the status of nodes and distances while considering nodes 2,4,5

Nodes Not yet finalized: {2}

Distances={0,8,5,11,7}

NO update is required. hence distance between

1 and all other nodes are given in distance.

Another algorithm is Floyd–Warshall algorithm[9] , for getting the shortest paths in a weighted graph with positive or negative edge weights (but with no negative cycles). A single run of the algorithm will capture the lengths (summed weights) of the shortest paths between all pairs of vertices. We can call this algorithm also Roy–Warshall algorithm, the Roy–Floyd algorithm, or the WFI algorithm. Consider a graph G with vertices M numbered 1 through N. Consider a function shortestPath(i,j,k) that returns the shortest possible path from i to j using vertices only from the set {1,2,3,4...k} as intermediate points along the way. w(i,j) is the weight of the edge between vertices i and j we can define shortestPath(i,j,k+1) using the recursive formula : shortestPath(i,j,0) = w(i,j) and the recursive function is shortestPath(i,j,K+1) = min(shortestPath(i,j,k), shortestPath(i,k+1,k) + shortestPath(k+1,j,k)). The algorithm works by computing shortestPath(i,j,k) for all (i,j) pairs for k=1, then k=2 etc. This process continues until k=N.

Let the dist be |M| * |M| array of minimum distnaces initialized to INFINITY.

```
for each vertex i
  dist[i][i] <- 0
for each edge (a,b)
  dist[a][b] <- w(a,b)
for k from 1 to |M|
  for i from 1 to |M|
     for j from 1 to |M|
      if dist[i][j] > dist[i][k] + dist[k][j]
         dist[i][j] <- dist[i][k] + dist[k][j]
  endif
```

Let n be number of vertices that is |M| . To find all n2 of shortestPath(i,j,k) from those of shortestPath(i,j,k-1) requires 2n2 operations.We begin with shortestPath(i,j,0) = edgeCost(i,j) and compute the sequence of n matrices shortestPath(i,j,1) , shortestPath(i,j,2) till shortestPath(i,j,n) , the total number of operations used is n*2n2 = 2n3. So the total complexity is O(n3). Running Dijkstras algorithm for all nodes where V is number of vertices and E is the number of edges gives the complexity is O(E log V), while Floyd's complexity is O(V3If E is equal to O(V2) then these two algorithms are theoretically identical, but in practice Floyd's is faster. If you E = O(V), then running Dijkstra for all nodes is better both in theory and in practice. If there is a complete graph please prefer Floyd's algorithm and run Dijkstra from all nodes if there are as many edges as you have nodes. If you have enough memory and time Floyd's algorithm is clearly better because it takes much less time to code. But If you do not want every possible path, Floyd-Warshall may waste time by calculating too many unwanted shortest paths. In that case we can use Dijkstra's algorithm. Another Algorithm is Bellman-Ford Algorithm, to find the shortest path from source to all vertices in the graph. The graph may contain negative edges. But here no meaning of negative edge. Bellman ford is simpler than Dijkstra's and suits well for ditributed systems. But time complexity of Bellman-Ford is O(VE) is more than Dijkstra's Algorithm.

IMPLEMENTATION

Refer with:Fig17. for the implementation of fully connected digraph network topology[4] among DataNodes inside Hadoop Distributed File System. The HDFS client sends create a request on DistributedFileSystem APIs. DistributedFileSystem makes an RPC call to the NameNode to create a new file in the filesystem’s namespace. The NameNode performs various checks to make sure that the file doesn’t already exist and that the client has the permissions to create the file. If the outcome is positive in the check, the NameNode makes a record of the new file; else, file creation fails and the client is thrown an IOException. The DistributedFileSystem gives an FSDataOutputStream for the client to start writing data to DataNode . As the client writes data, DFSOutputStream splits the data into packets, which writes to an internal queue, called the data queue consumed by

the DataStreamer, which is responsible for requesting the NameNode to allocate new blocks by picking a list of suitable DataNodes to store the replicas. Here the DataNodes are connected in fully connected digraph network topology so the data packet will be transferred to all DataNodes simultaneously.

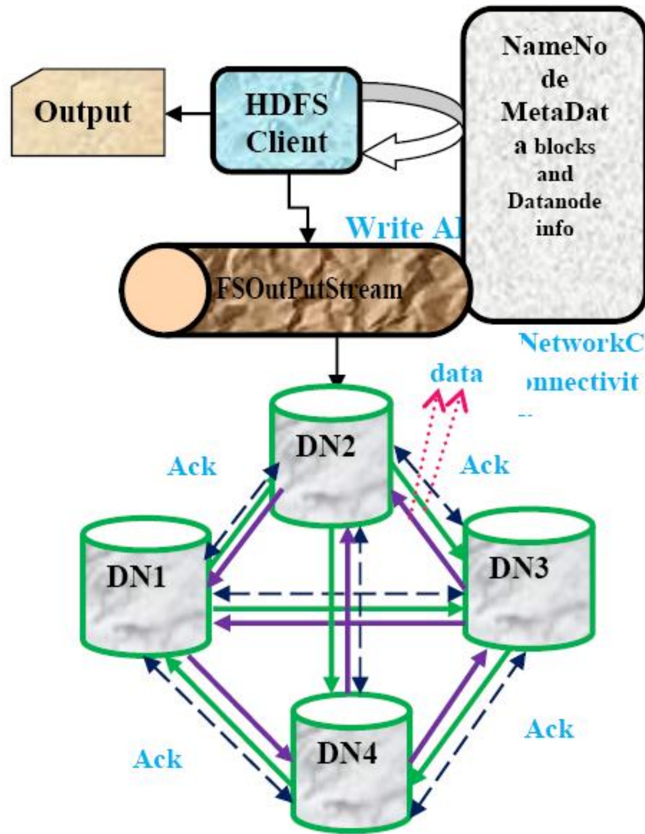


Figure.11: Fully Connected Digraph network topology implementation in HDFS

In the existing architecture the data packet needs to traverse through all the DataNodes to reach the last DataNode (based on the replication factor we need to decide last number). If we consider one millisecond is the time required to transfer packet from one DataNode to another DataNode between two racks and 0.75 for intra rack DataNode transfer, then to reach the 4th DataNode (replication factor is 4) is 2.75 milliseconds. The same is applicable for acknowledgement transfer as well. So total 5.5 milliseconds required to complete one packet copy operation with replication factor 4. Where as in fully connected digraph network topology data packet will be transferred in parallel fashion i.e, it will take one millisecond to transfer the packet to all DataNodes irrespective of replication factor. Acknowledgement as well will be transferred to source DataNode in one millisecond. So total 2 milliseconds required for successful one packet copy operation irrespective of replication factor. If we consider intra rack DataNode transfer less than one millisecond then the total time is max 2 milliseconds. DN1 is connected to all DataNodes and the same is applicable to all DataNodes. So the total number of connections are n(n-1) excluding acknowledgement edges. If there is any network failure while writing datapacket to DataNodes which were connected using fully connected network topology, no need look for the new DataNode for replacement , instead of that there will be number of alternative paths to reach the target DataNode . As shown in the Fig.11 DN2 will receive the write request (datapacket) from the IOstream. DN2 will send the packet to DN1,DN4 and DN3 simultaneously. So the total time is max one millisecond (considering DN1 in Rack1, DN2,DN3 are in Rack2 and DN4 in Rack3) for writing datapacket and the acknowledgement time is max one millisecond. While writing datapacket to DN4 from DN2 if there is network failure issue , using the parameter no need to replace the new DataNode , instead of that,datapacket can reach DN4 using DN2->DN1->DN4, DN2->DN3->DN4, DN2->DN3->DN1->DN4, DN2->DN1->DN3->DN4. Like this depends on the replication factor we can have multiple number of paths i.e, if the replication factor is 3 we can have one alternate path, if it is 4 we can have 4 alternative paths (as shown above) , for 5 there will be 15 alternate paths and for replication factor 6 we can have 40 alternate paths from DN2 to DN4. Since we have alternative paths we no need to think about replacement .This is how we can avoid replacement of new node in case of network failure.

EVALUATION

The simulation results are here with the assumption that inter rack datanodepacket transfer will take one millisecond and intra rack DataNode packet transfer will take 0.75 millisecond. There is best case scenario, medium and worst case scenariosbased on the path which we consider toreach to target node. Suppose DN2 to DN4 datapacket needs to be copied and considering DN1 in Rack1, DN2,DN3 are in Rack2 and DN4 in Rack3 Direct path from DN2 to DN4 is the best case scenario where it will take max one millisecond to copy the data and one millisecond for acknowledgement. So total 2 milliseconds required for datapacket copy operation including acknowledgement. Where as in medium case scenario, DN2->DN1->DN4, DN2->DN3-DN4 it will take one millisecond for DN2->DN1 different rack, DN1->DN4 one millisecond for different rack . So total 2 milliseconds required for copy and 2 milliseconds for acknowledgement. So total 4

Table 2: Access Time Analysis using Fully ConectedDataNode Topology.

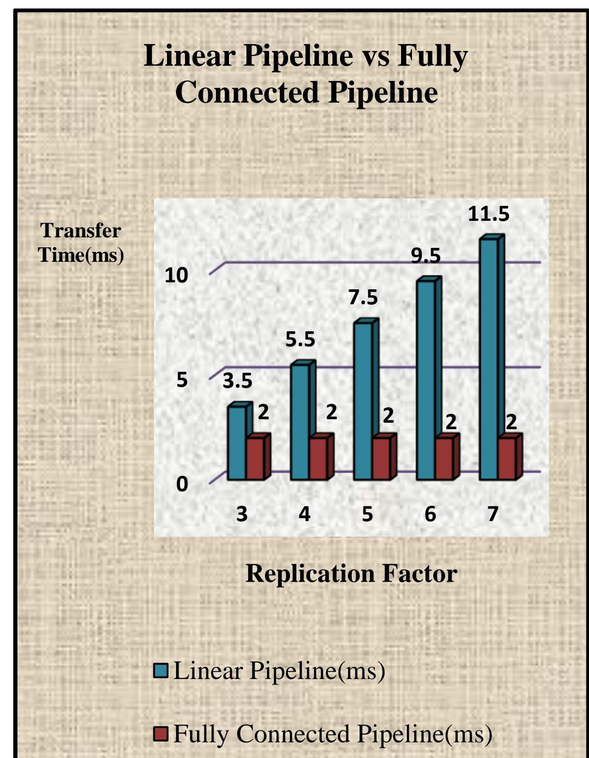
BestCase Scenario	DataNode Connectivity	Transfer Time
Rack1 DN1 Rack2 DN2,DN3 Rack3 DN4	DN2->DN4 : 1 ms, different rack	1 +1 : 2ms (copy+ack)
MediumCase Scenario	DataNode Connectivity	Transfer Time
Rack1 DN1 , Rack2 DN2,DN3 Rack3 DN4	DN2->DN1->DN4, DN2->DN3->DN4 DN2->DN1 : 1 ms DN1->DN4 :1 ms DN2->DN3: 0.75ms same rack	1+1 : 2 2+2:4 (copy+ack) 0.75+1:1.75 1.75+1.75:3.50 (copy+ack) 0.75+0.75:1.5 1.5+1.5=3ms (copy+ack)
WorstCase Scenario	DataNode Connectivity	Transfer Time
Rack1 DN1 Rack2 DN2,DN3 Rack3 DN4	DN2->DN1->DN3->DN4 DN2->DN3->DN1->DN4	1+1+1:3 3+3 : 6 ms (copy+ack) 0.75+1+1:2.75 2.75 + 2.75 : 5.50 ms (copy+ack)

milliseconds in medium case scenario. In the worst case scenario DN2->DN1->DN3->DN4 (3+3) , DN2->DN3->DN1-DN4 (2.75+2.75) total time is max 6 milliseconds and min 5.5 milliseconds including acknowledgement. Refer with: Table 2 for the Access Time Analysis using Fully Connected DataNode Topology. In the linear pipeline connectivity time required for datapacket copy operation including acknowledgement is 5.5 milliseconds, which is almost two times to worst case scenario of fully connected digraph network topology. Refer with: Table 3 for the results of linear fashion DataNode pipeline connectivity and the fully connected digraph network topology with different level of replication factors using the best casescenario of fully connected digraph network topology. That means no network failure and using the direct path from source DataNode to destination DataNode . In this proposed architecture the time required to complete one packet copy operation is 2 milliseconds if there are no intra rack DataNodes , and max 2 milliseconds in case of the DataNodes list includes intra rack DataNodes. Based on the results mentioned here for replication factor 4 FullyConnectedDataNode Digraph topology is better than Liner Pipeline data packet transfer time.

Table 3: LinearPipeline vs FullyConnectedPipelinePacket Best Case Transfer time

Replication Factor	Linear Pipeline(ms)	Fully Connected Pipeline(ms)
3	3.5	2
4	5.5	2
5	7.5	2
6	9.5	2
7	11.5	2

Refer with: Graph 2 for the time required to complete copy operation in Linear Pipeline DataNode connectivity is increasing once we increase the replication factor. Where as in Fully Connected digraph DataNode network topology the time is constant irrespective of the replication factor.



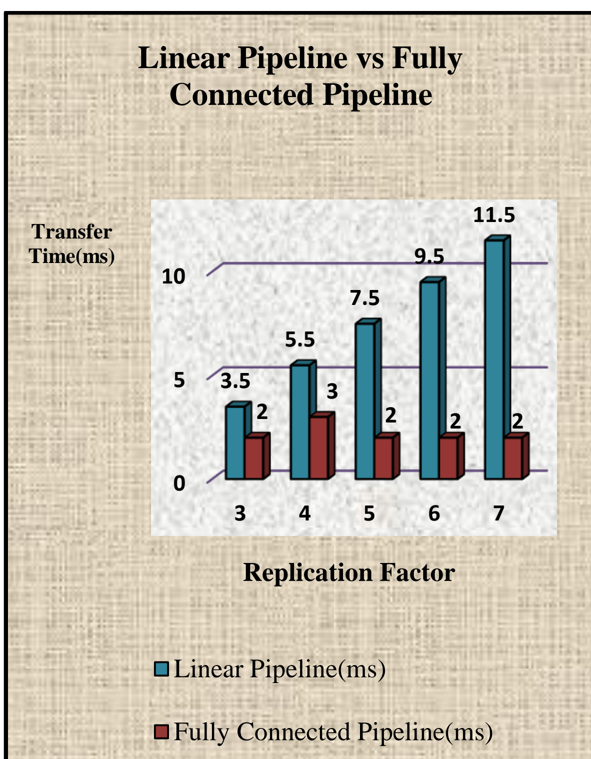
Graph 2:.PacketTransferTime for Linear Pipeline vsFullyConnectedDatanode Pipeline.

Possible paths from DN2 to DN4 using replication factor 4 incase of network failure is there from DN2->DN4 is DN2-

>DN1->DN4, DN2->DN3->DN4. Refer with: Table 4 for the results of linear fashion DataNode pipeline connectivity and the fully connected digraph network topology with different level of replication factors especially with medium case scenario of fully connected digraph network topology for replication factor 4. In this proposed architecture the time required to complete one packet copy operation from DN2->DN1 is 1 millisecond and DN1->DN4 is 1 millisecond. So total is is 2 milliseconds and including acknowledgement is 4 milliseconds. In case of DN2->DN3->DN4 the total time including acknowledgement is 3 milliseconds. Based on the results mentioned here for replication factor 4 Fully Connected DataNode Digraph topology is better than Liner Pipeline data packet transfer time.

Table 4: LinearPipeline vs FullyConnectedPipelinePacket medium case Transfer time

Replication Factor	Linear Pipeline(ms)	Fully Connected Pipeline(ms)
3	3.5	2
4	5.5	3
5	7.5	2
6	9.5	2
7	11.5	2



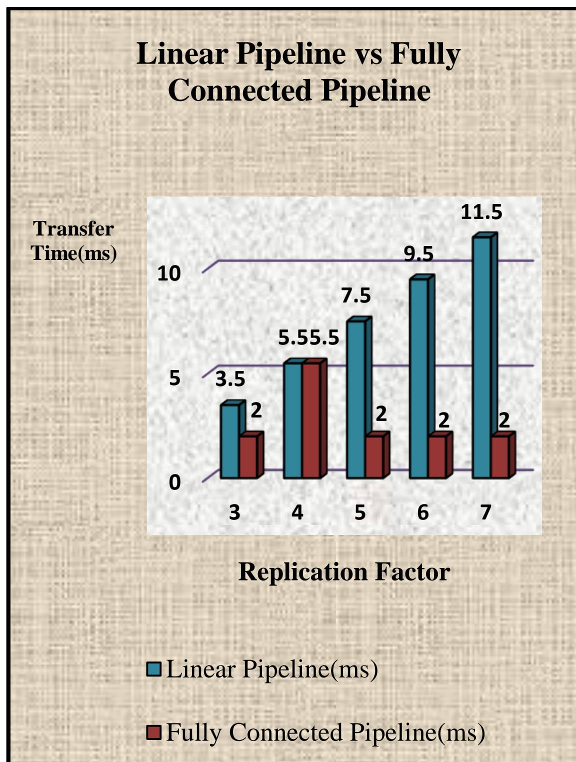
Graph 3: PacketTransferTime for Linear Pipeline vsFullyConnectedDatanode Pipeline.

Refer with: Graph 3 for the time required to complete copy operation in Linear Pipeline DataNode connectivity is increasing once we increase the replication factor. Where as in Fully Connected digraph DataNode network topology the time is constant irrespective of the replication factor.

If we consider the network failure from DN2-DN4 in two combinations DN1->DN4 or DN3->DN4, then the possible paths from DN2->DN4 are DN2->DN1->DN3-DN4 and DN2->DN3->DN1->DN4. Refer with: Table 5 for the results of linear fashion DataNode pipeline connectivity and the fully connected digraph network topology with different level of replication factors especially with worst case scenario of fully connected digraph network topology for replication factor 4. In this proposed architecture the time required to complete one packet copy operation from DN2->DN1 is 1 millisecond , DN1->DN3 is 1 millisecond and DN3->DN4 is 1 millisecond. . So total is 3 milliseconds and including acknowledgement is 6 milliseconds. In case of DN2->DN3->DN1->DN4 ,DN2->DN3 is 0.75 millisecond , DN3->DN1 is 1 millisecond and DN1->DN4 is 1 millisecond. The total time is 2.75 millisecond and including acknowledgement is 5.50 milliseconds.Only in the worst case scenari Linear pipeline connectivity id equal to FullyConnectedDataNode Digraph topology. Two network failures I have taken to create the worst case scenario. But this very rare case. So we can conculde that FullyConnectedDataNode Digraph topology is giving always better results than liner fashion DataNode pipeline connectivity.

Table 5:.LinearPipeline vs FullyConnectedPipelinePacket worst caseTransfer time

Replication Factor	Linear Pipeline(ms)	Fully Connected Pipeline(ms)
3	3.5	2
4	5.5	5.5
5	7.5	2
6	9.5	2
7	11.5	2



Graph 4: .PacketTransferTime for Linear Pipeline vsFullyConnectedDatanode Pipeline.

Refer with: Graph 4 for the time required to complete copy operation in Linear Pipeline DataNode connectivity is increasing once we increase the replication factor. Where as in Fully Connected digraph DataNode network topology the time is constant irrespective of the replication factor.

CONCLUSION

Based on the analysis of the values using different replication factors we can say that the time required to copy data packet to all DataNodes as per the list available from the metadata from the NameNode is constant. Where as in linear Pipeline DataNode connectivity the time increases while increasing the replication factor. In Linear Pipeline DataNode connectivity we need to support network failure by using the parameterdfs.client.block.write.replace-datanode-on-failure.enable using true or NEVER options based on the available DataNodes in the cluster (cluster size), where as in fully connected digraph DataNode network topology if there is any chance of network failure in one edge we can have multiple paths to reach to destination node, i.e, if the replication factor is 3 we can have one alternate path, if it is 4 we can have 4 alternative paths , for 5 there will be 15 alternate paths and for replication factor 6 we can have 40 alternate paths. So we can nullify the network failure issues. In this architecture the time required to copy the datapacket to DataNodes in the network is max one millisecond and acknowledgement is max one millisecond. With the replication factor 4 max 2 milliseconds required to complete the datapacket write operation in the best casescenario, that means there is no network failure , where as 3 milliseconds for the same operation in medium case scenario , that is where there is one network failure issue and 5.50 milliseconds requiredin worst case scenario where there are two network failure issues. Here we have verified that no need of replacement of DataNode in case of network failure issues. So the usage of dfs.client.block.write.replace-datanode-on-failure.enable, dfs.client.block.write.replace-datanode-on-failure parameters is not required. This is how we can reduce or nullify the network failure issues among DataNodes. Since we have number of alternative paths among the DataNodes, users can escape from experiencing an unusually high rate of network failures. Using this shortest paths we can reduce the copy operation time as well as we have proved using the Access Time Analysis using Fully Connected DataNode Topology. As we change the architecture to fully connected digraph DataNode network topology the complexity and the cost to implement the architecture will also increase. We can ignore this cost and complexity since there is an improvement in data packet write operation performance and nullifying the network failure issues among the DataNodes. The future work includes reducing the cost of the network by using network cost optimization techniques.

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