Decentralized Key Management for Large Dynamic Multicast Groups using Distributed Balanced Trees

Thesis by

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Flow of Presentation

- Background
- Proposed Scheme
- Analysis
- References

Background

- Two Party Secure Communication
- Multicast Groups (Without Security)
- Secure Multicast
- Key Management for Secure Multicast
- Logical Key Hierarchy
- Problems in Existing Scheme

Two Party Secure Communication

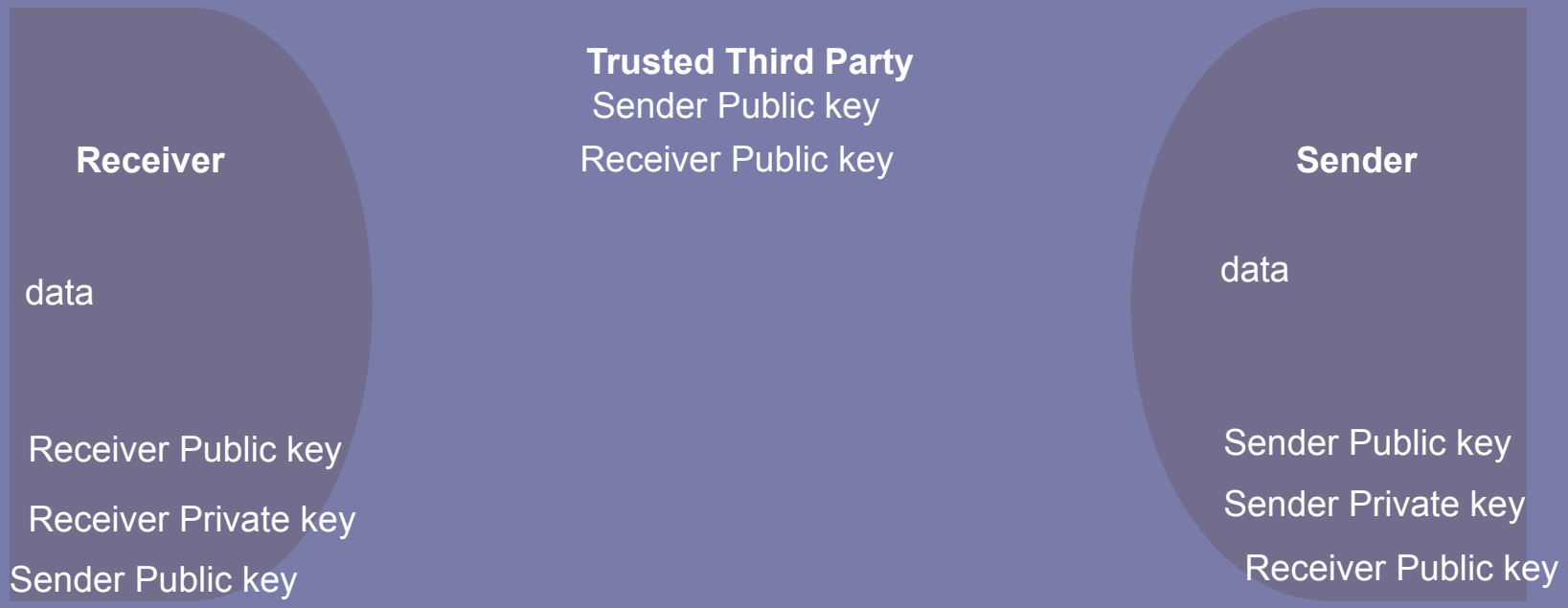
- Both parties generate a pair of keys such that data encrypted with one of them can be decrypted with the other

Two Party Secure Communication

- Both parties register one key with a trusted third party. This key is called the public key while the other is called private key.

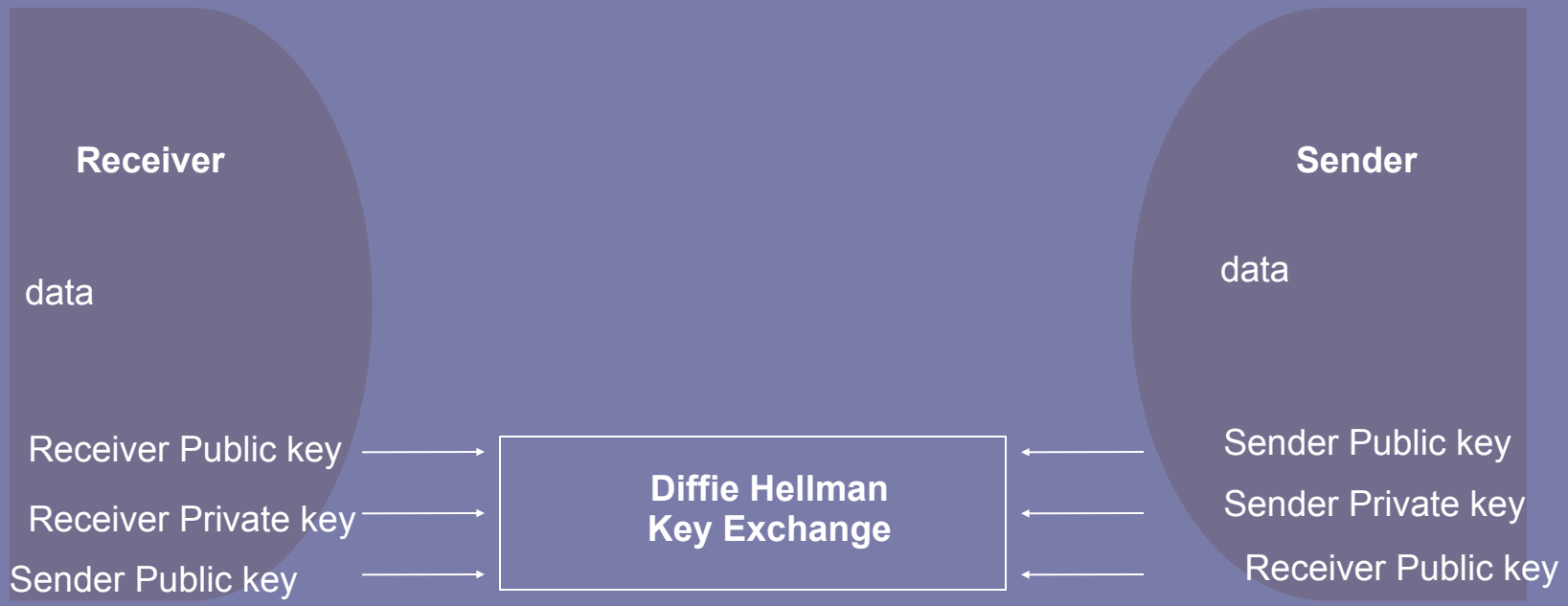
Two Party Secure Communication

- Both parties acquire the public key of the other party from the trusted third party



Two Party Secure Communication

- Both parties use the Deffie Hellman protocol to arrive at a common key at both ends



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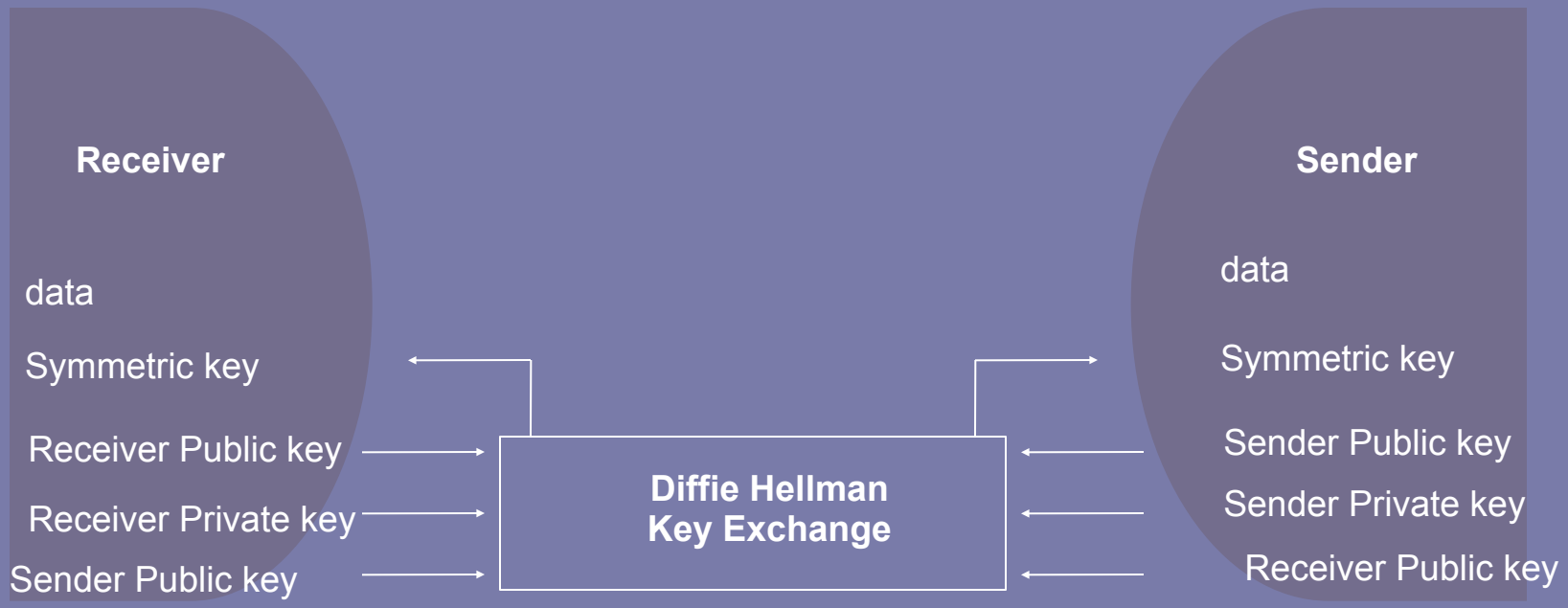
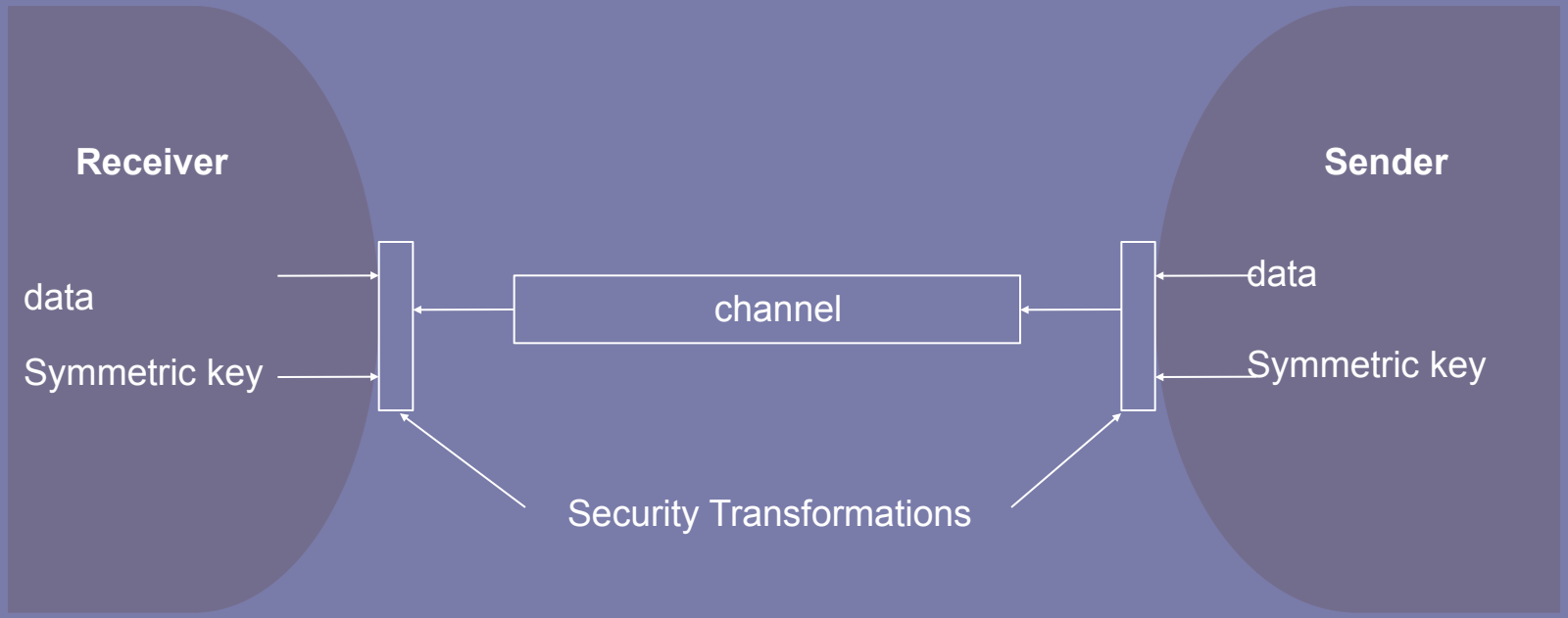


Two Party Secure Communication

- Both parties use the Deffie Hellman protocol to arrive at a common key at both ends

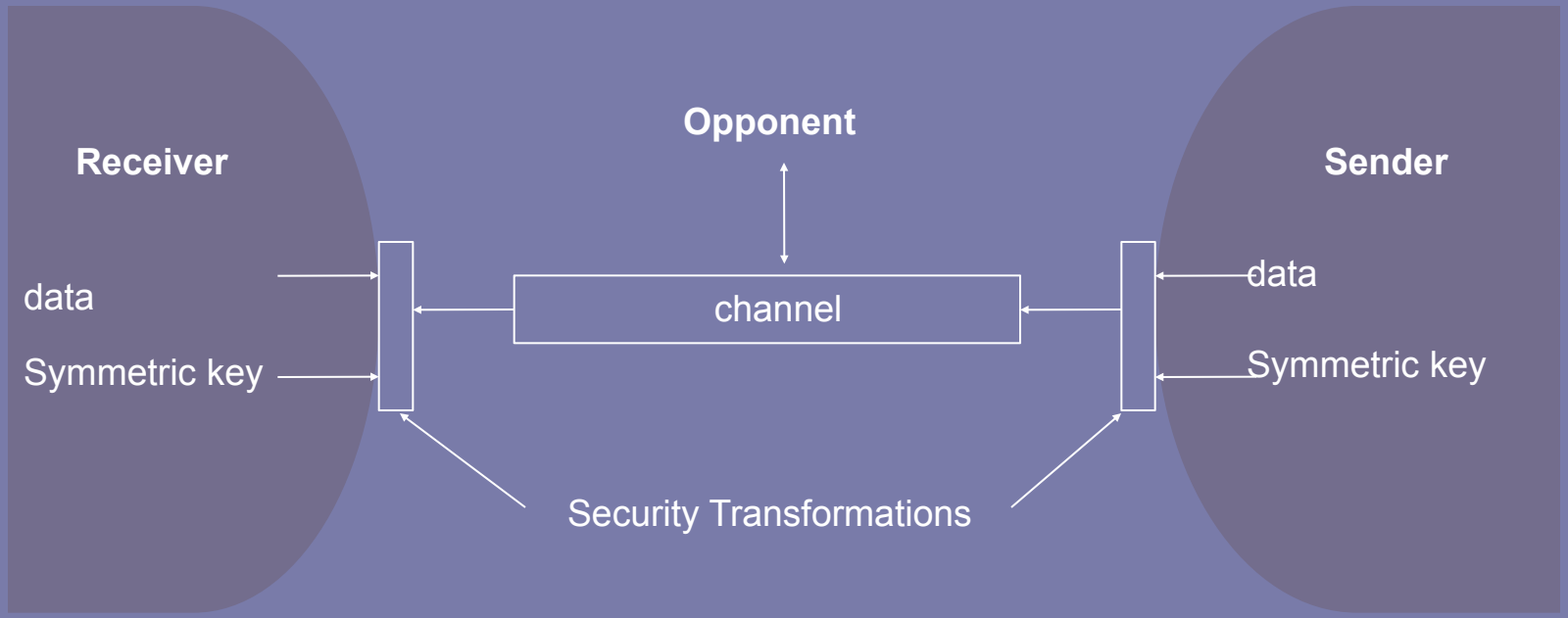
Two Party Secure Communication

- Both parties use symmetric encryption using this generated key to transfer data over the public channel

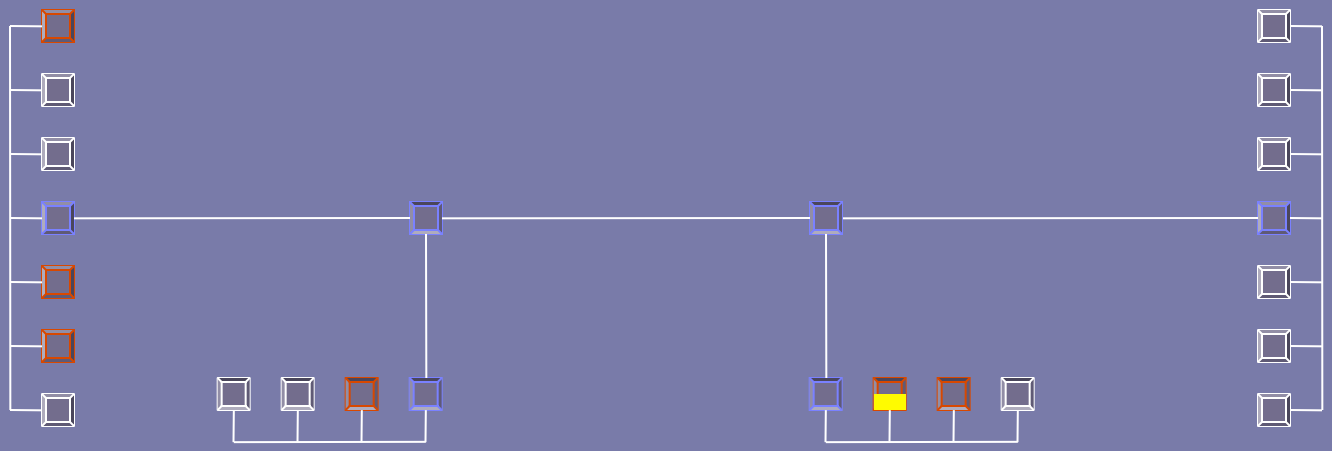


Two Party Secure Communication

- The opponent is unable to decipher encrypted data passing over the channel

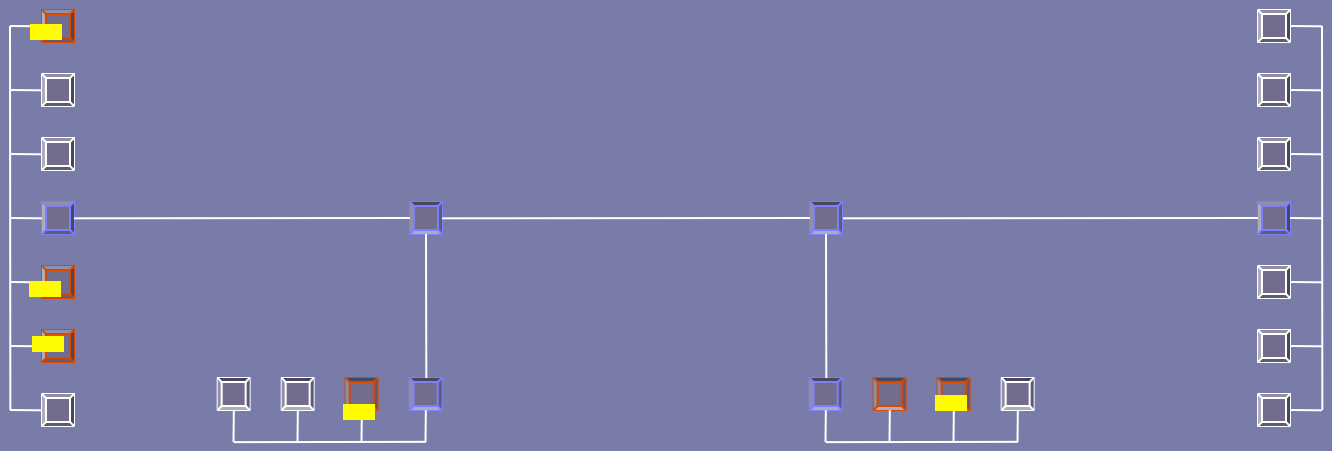


Multicast Groups (Without Security)



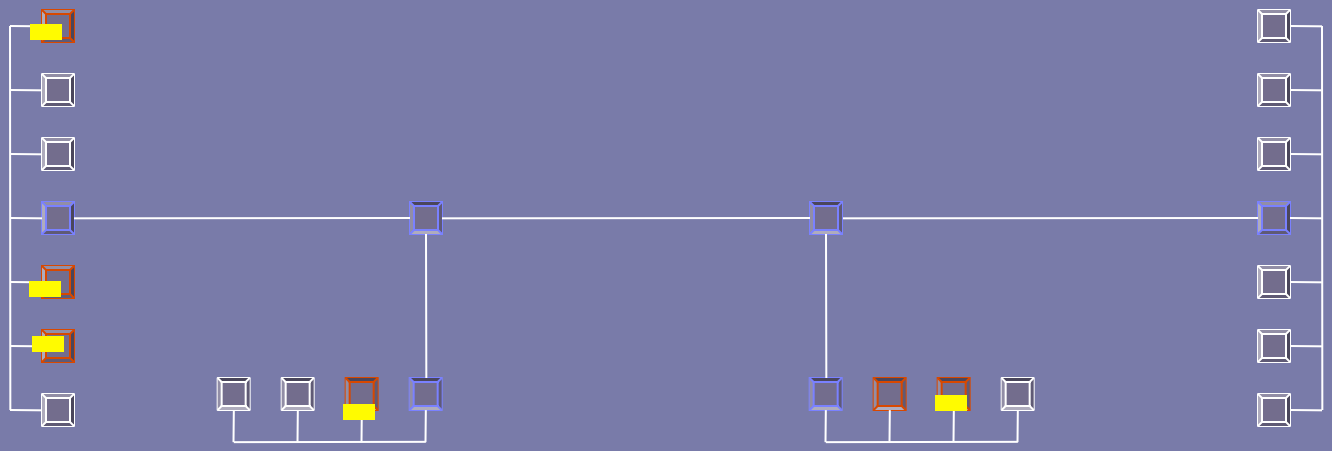
Multicast Groups (Without Security)

- Multicast is the delivery of a packet to all hosts which have shown interest in receiving it



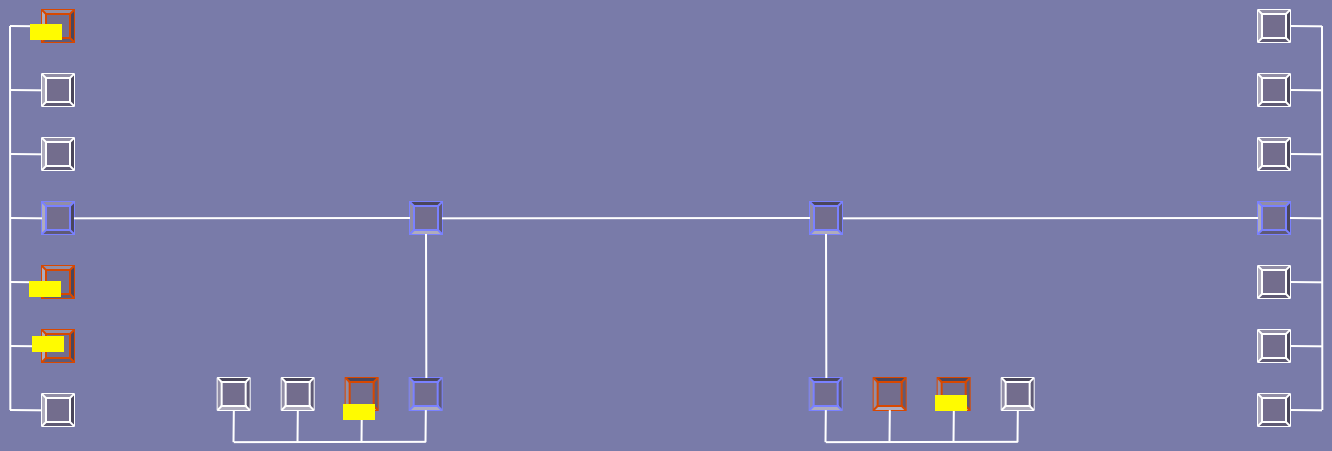
Multicast Groups (Without Security)

- Multicast capable routers construct each group's delivery tree
- Hosts can join or leave a multicast group by informing their nearest router



Multicast Groups (Without Security)

- In multicast there is no authentication or authorization for group membership and for sending data to a group

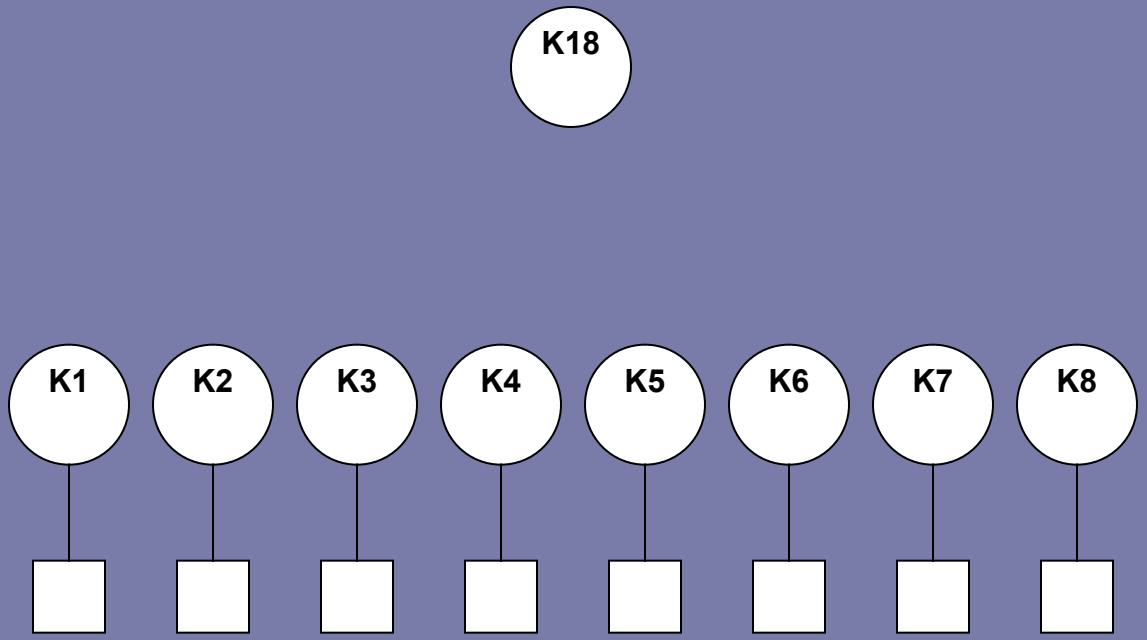


Secure Multicast

- All transmitted data must be encrypted and only group members should possess the key used to encrypt and decrypt, also called the group key
- After every member join or leave in the secure group, key must be changed otherwise
  - A joining member can decrypt accumulated traffic
  - A leaving member can continue to decrypt data
- The mechanism by which the new key is generated and distributed is called key management
- The message containing the new key is called key update

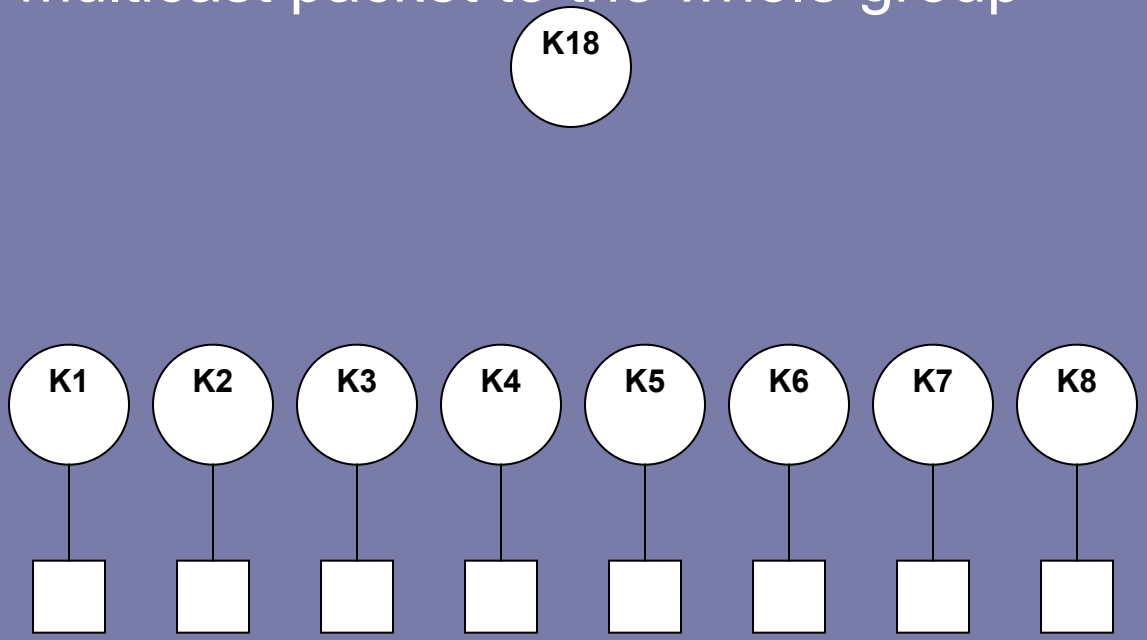
Key Management for Multicast Groups

- In simple schemes key updates are sent in a single multicast packet containing the group key encrypted by each member's public key. Size of key update is proportional to group size



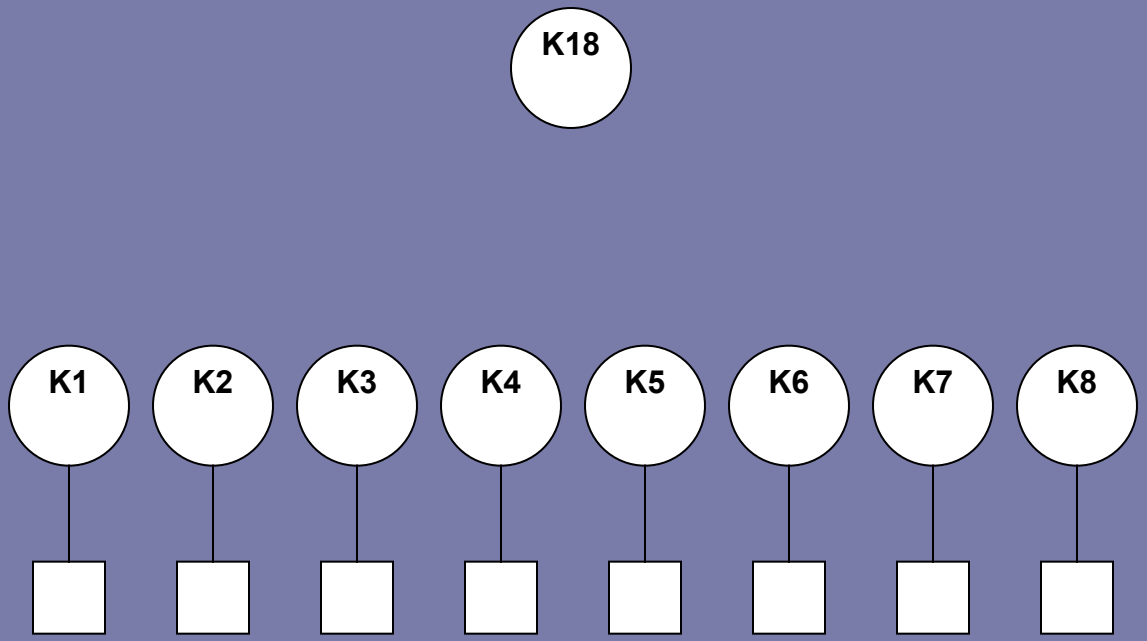
Key Management for Multicast Groups

- For example, if M8 wants to leave the group, the new K18 is sent encrypted with each of K1 through K7 but not with K8
- These seven encrypted copies of K18 are sent in a single multicast packet to the whole group



Key Management for Multicast Groups

- If every pair of hosts know a common key, the required encryptions reduce



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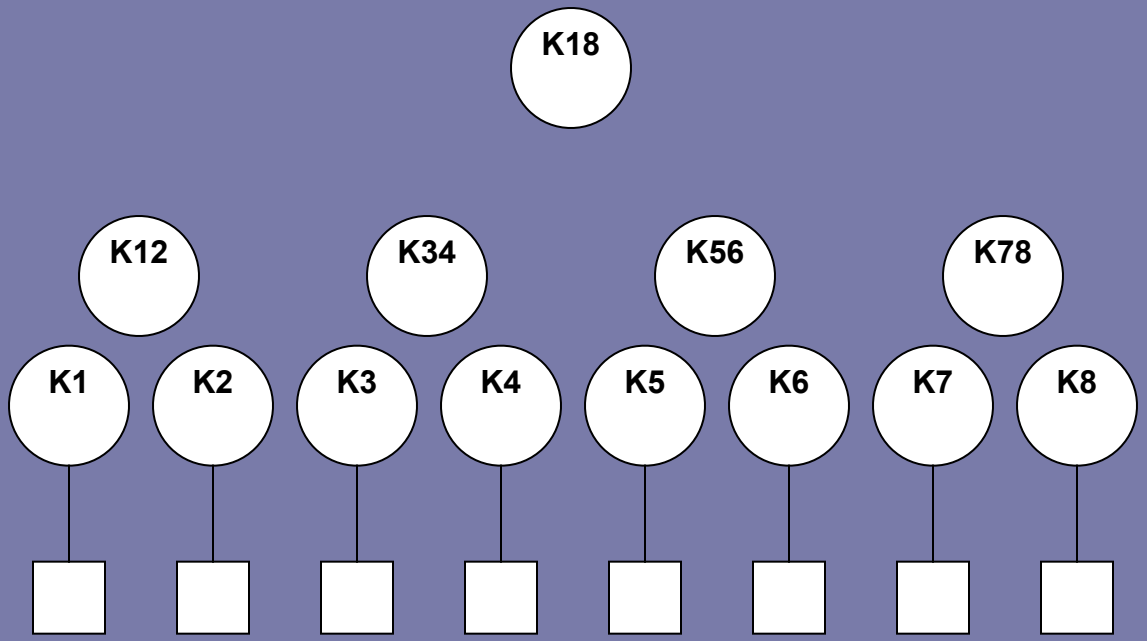
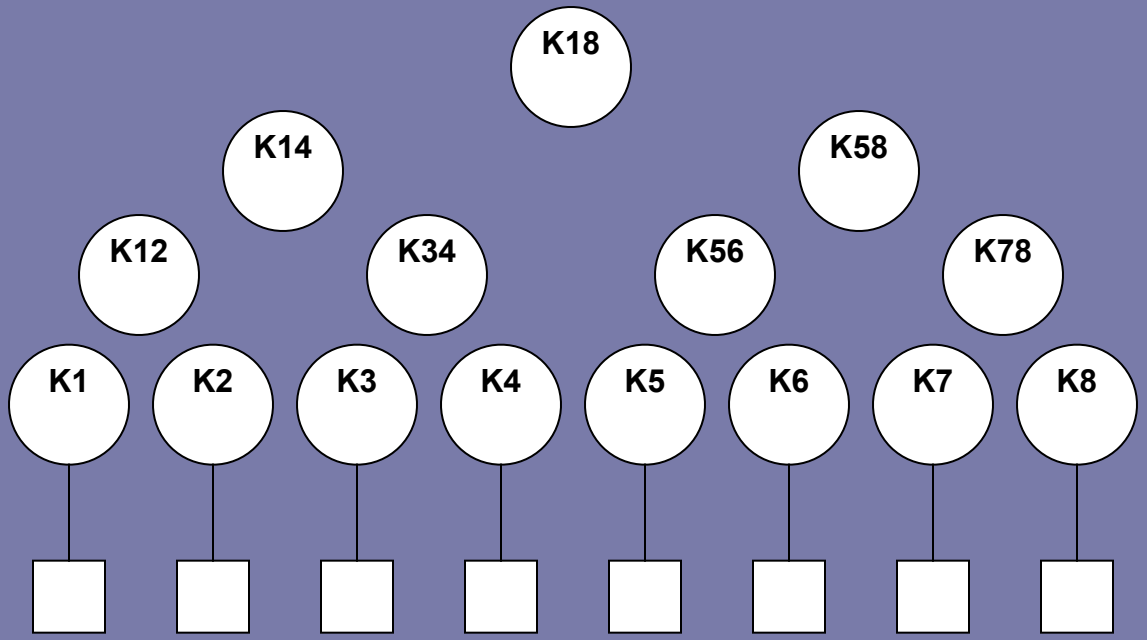


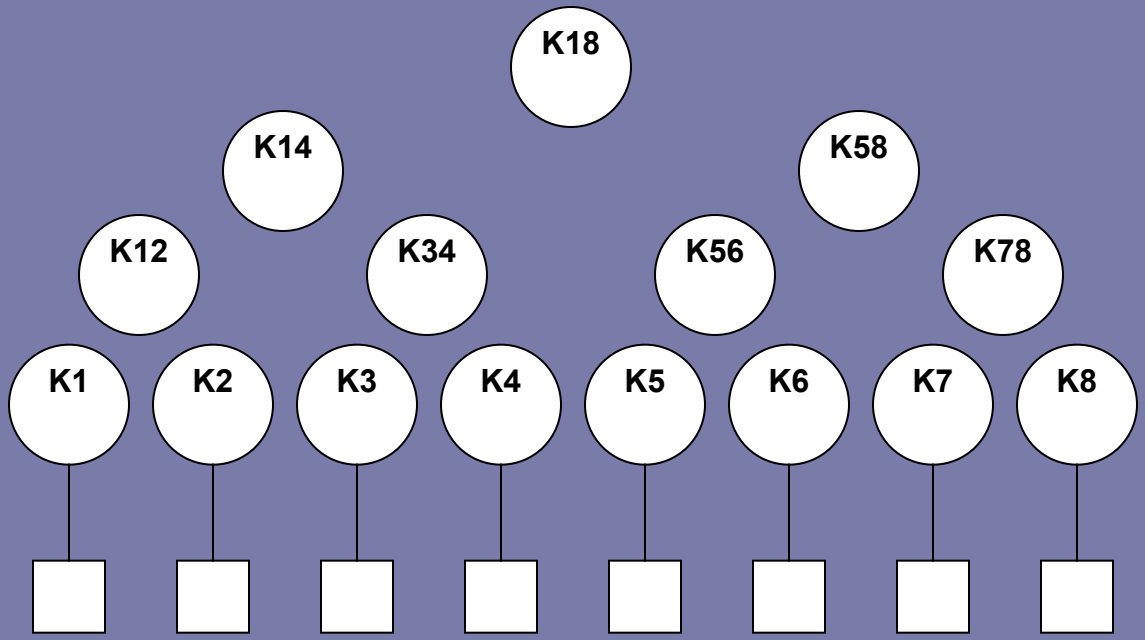
Key Management for Multicast Groups

- If every pair of hosts know a common key, the required encryptions reduce
- If this is extended to form a tree the number of encryptions become logarithmic



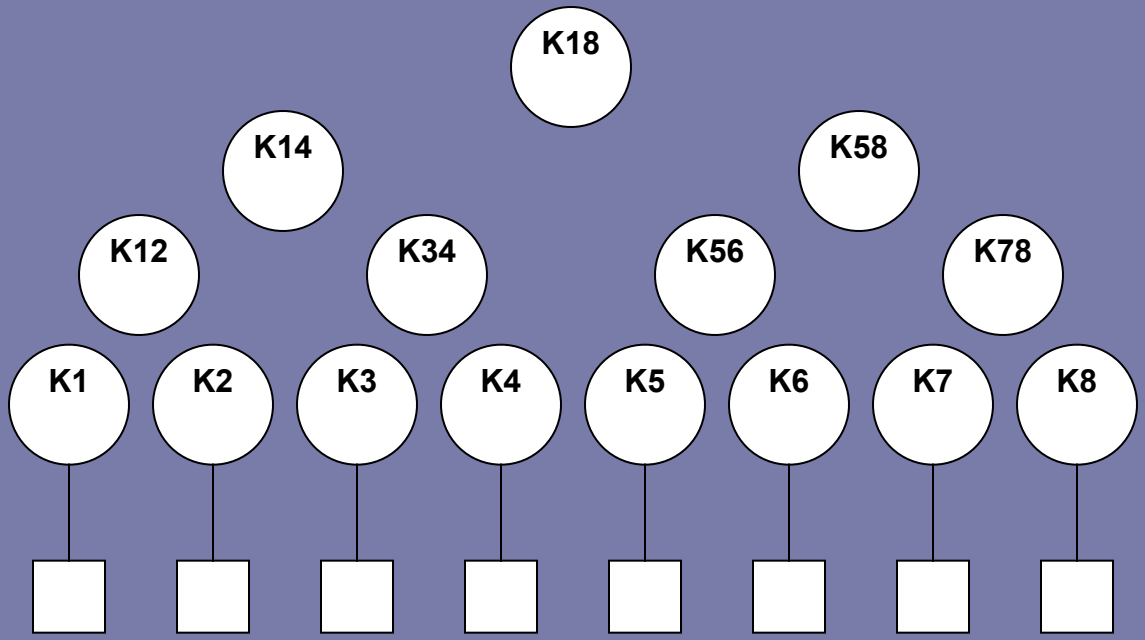
Key Management for Multicast Groups

- However two more keys need to be changed which were known by the leaving member
- The whole process goes like this



Key Management for Multicast Groups

- A total of five encryptions were needed
- Size of message is 2 lg n
- The scheme is called Logical Key Hierarchy



Logical Key Hierarchy (LKH)

- Each member knows all keys on its path to the root
- On member join or leave all keys on that member's path to the root are updated
- A changed key is sent encrypted by both its children keys therefore message size becomes 2 log n

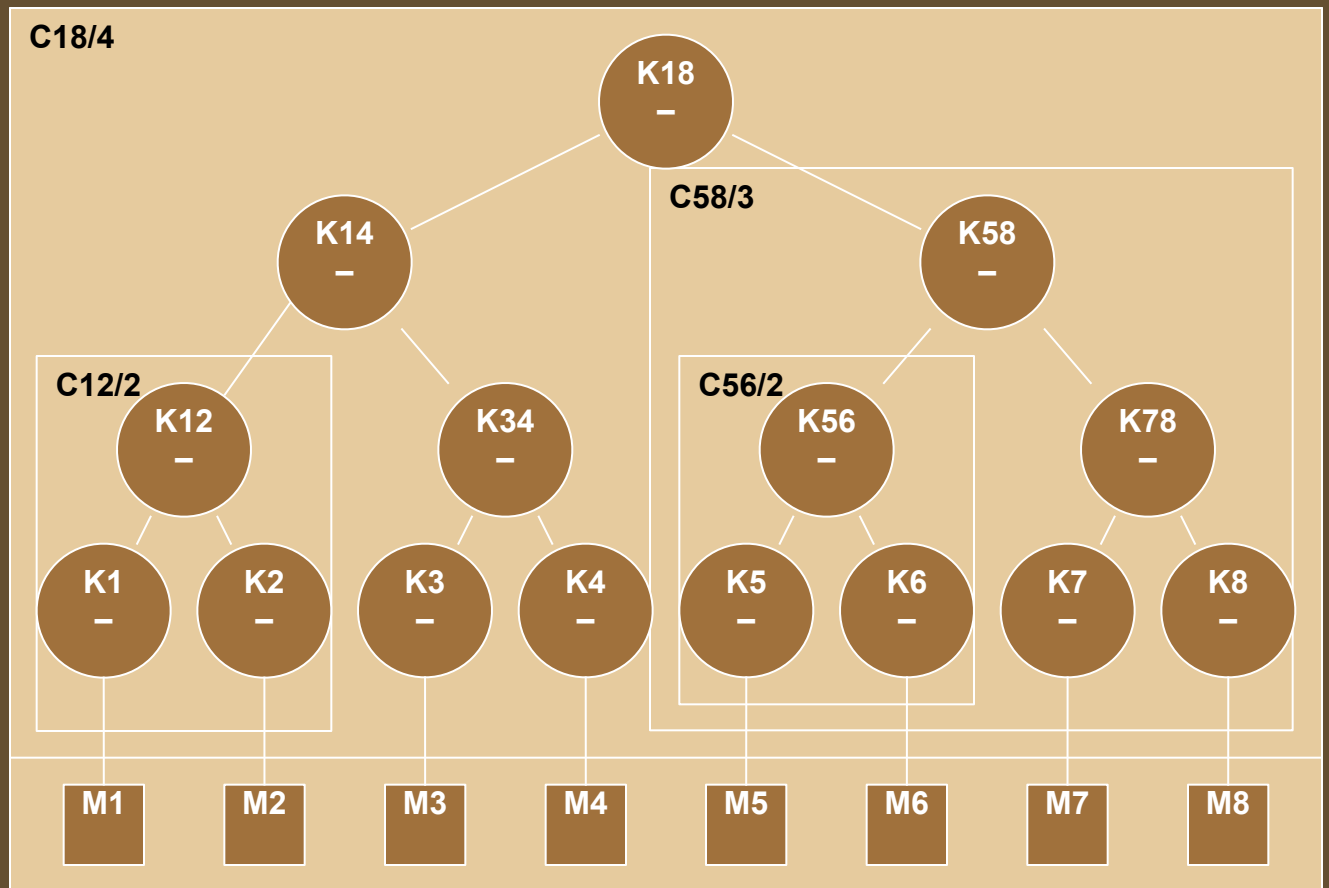
Problems in Existing Scheme

- Single controller responsible for storing keys for the whole group and generating key updates for them
  - Performance deteriorates as group size increases
- Key update message size is logarithmic only when the key tree is balanced which is not guaranteed in this scheme
  - Performance deteriorates as tree gets out of balance

Proposed Scheme

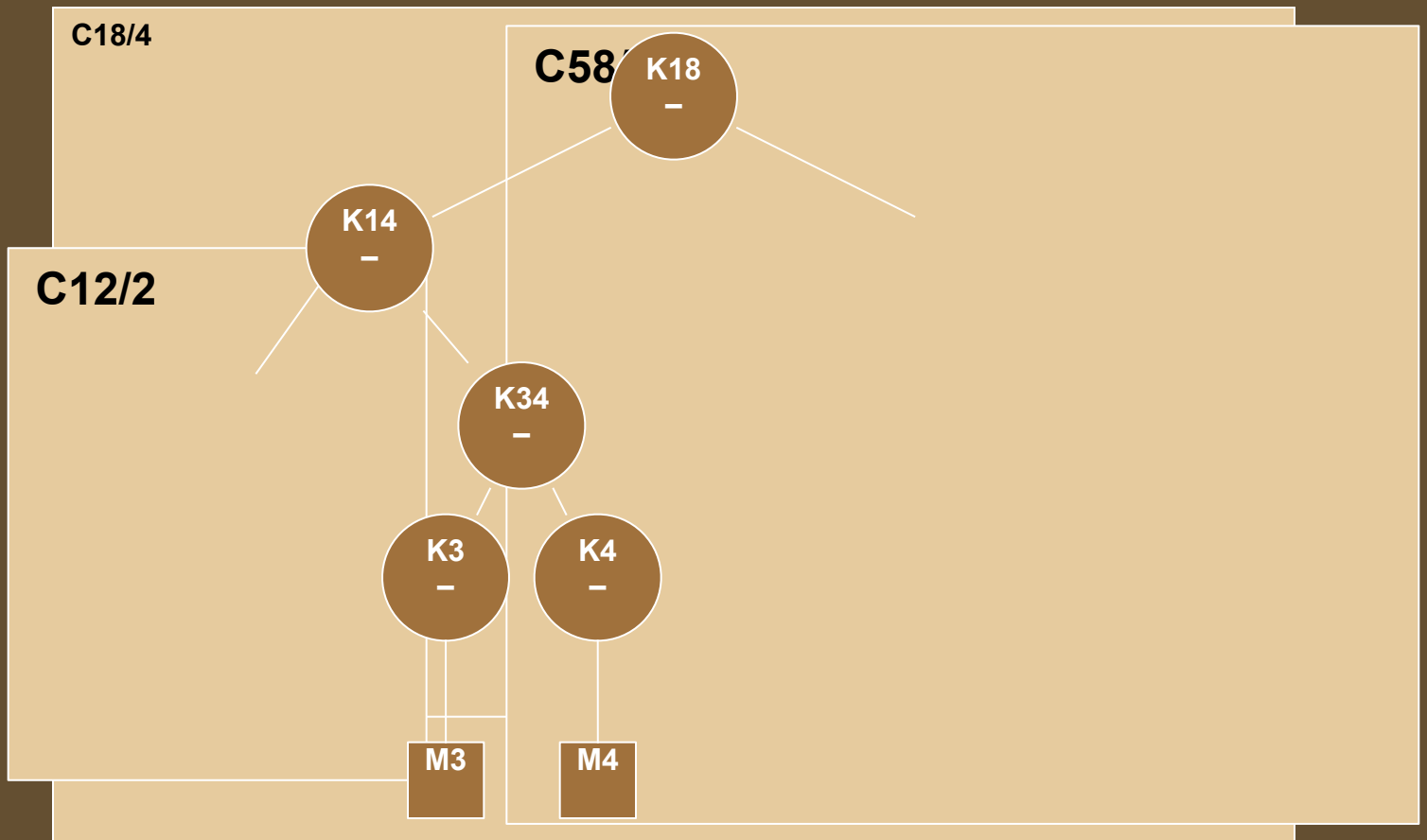
- Distributed Nature of Key Tree
- Balancing of Key Tree
- Key Updates
- Member Joins
- Member Leaves

Distributed Nature of Key Tree



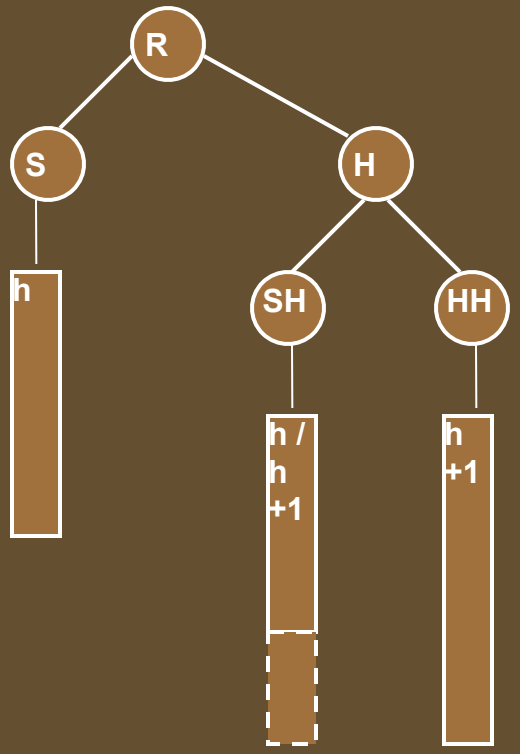
Distributed Nature of Key Tree

- Every controller has a key as allotted to it by the parent and another key that it generates to be used in the key tree



Balancing of Key Tree

- There is no order in members so there is a single case of rotation which is like single rotation in an AVL tree



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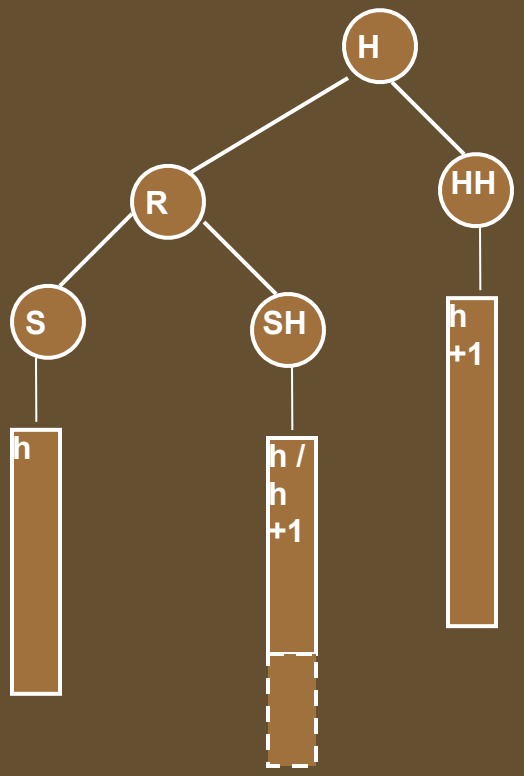
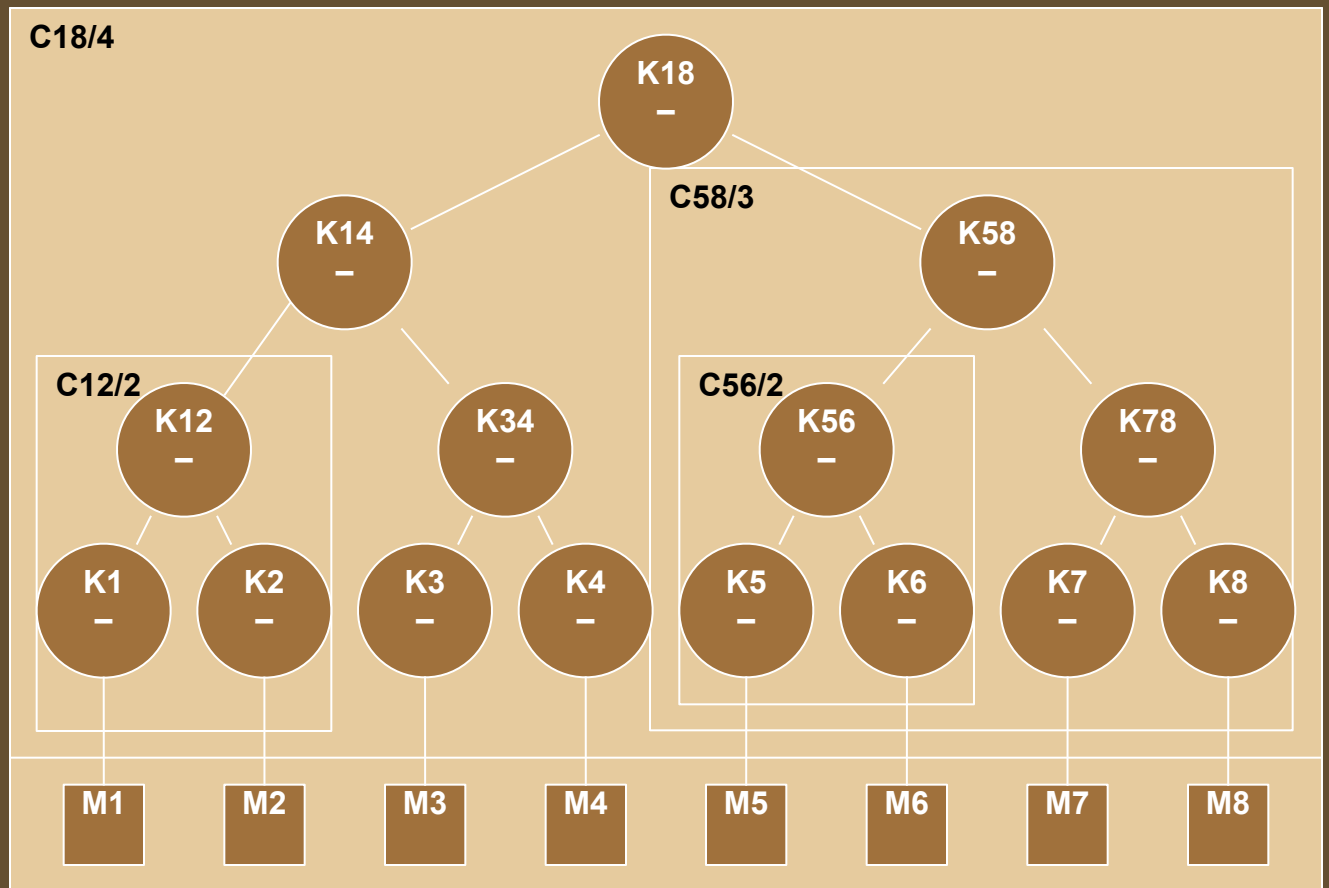
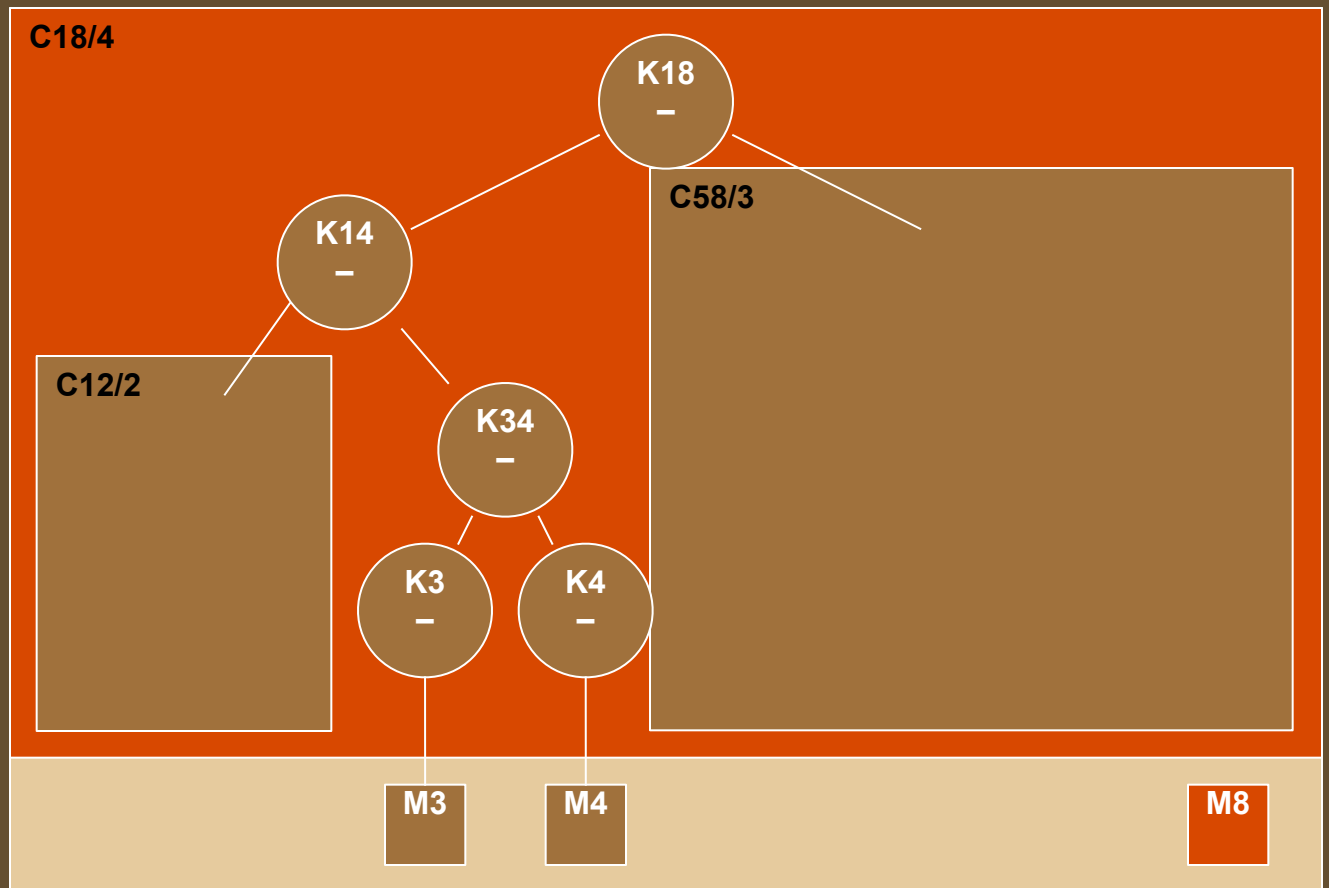


Key Updates

- Assume all keys need to updated

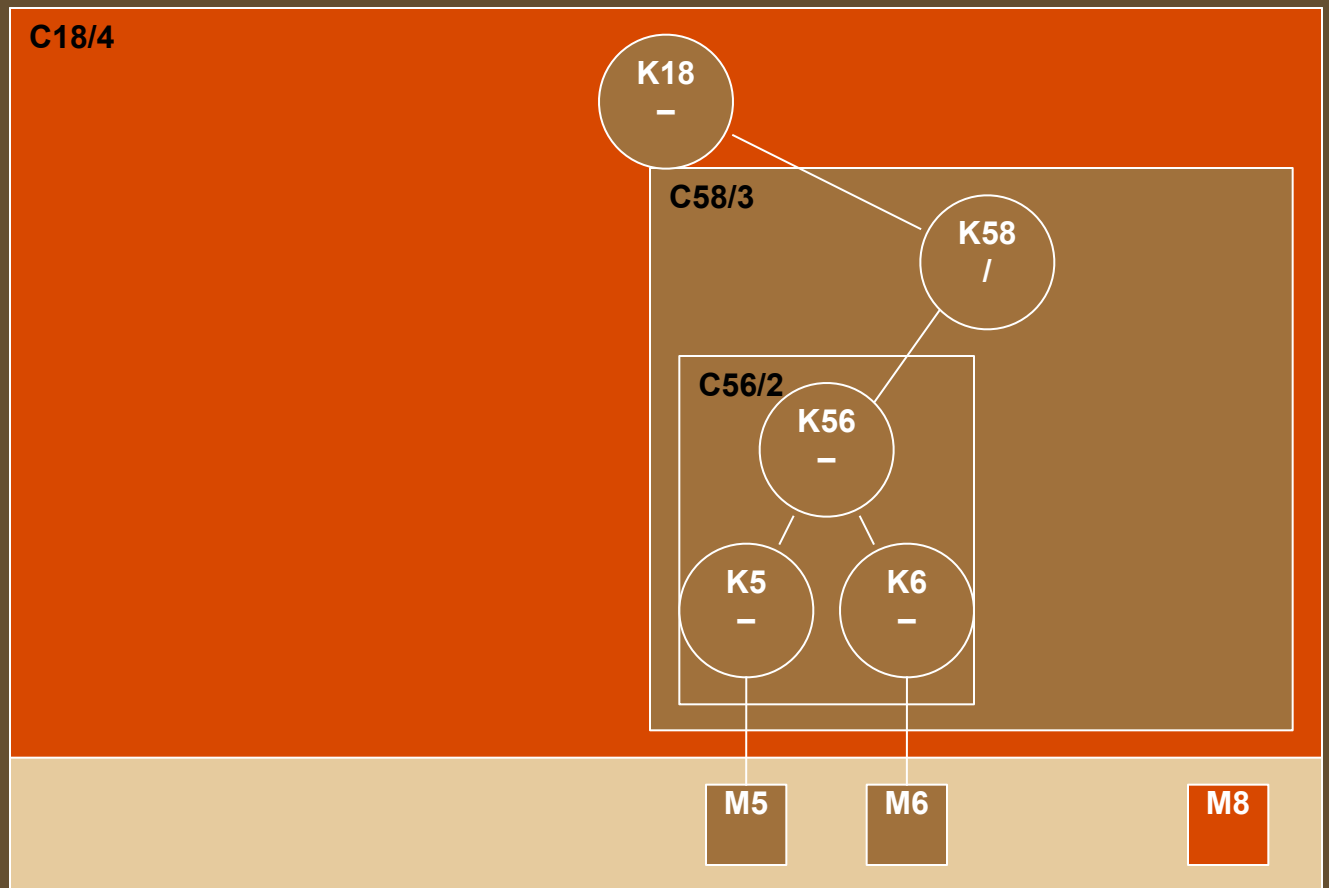


Member Joins



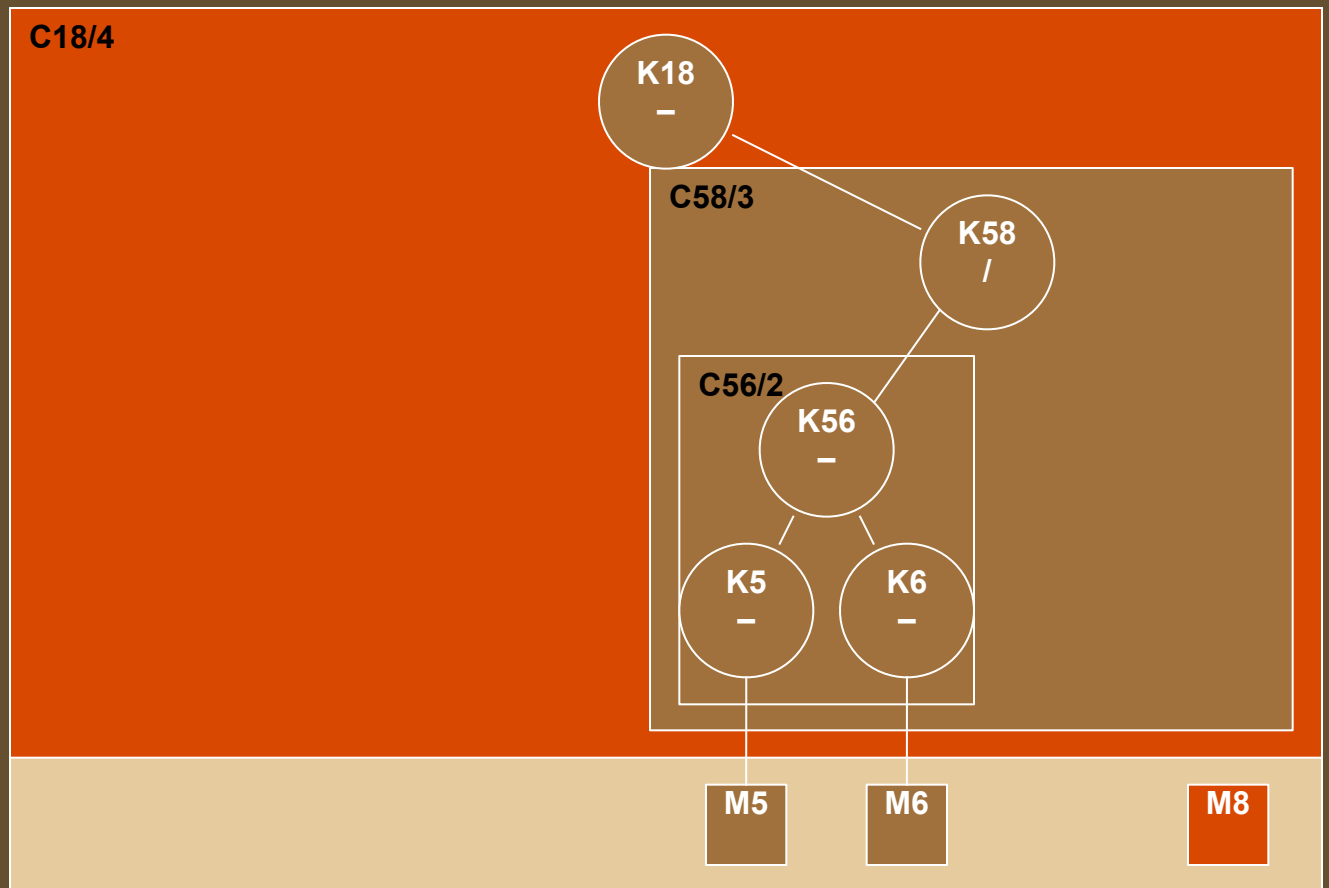
Member Joins

- Sub controller takes a random decision since the node is balanced



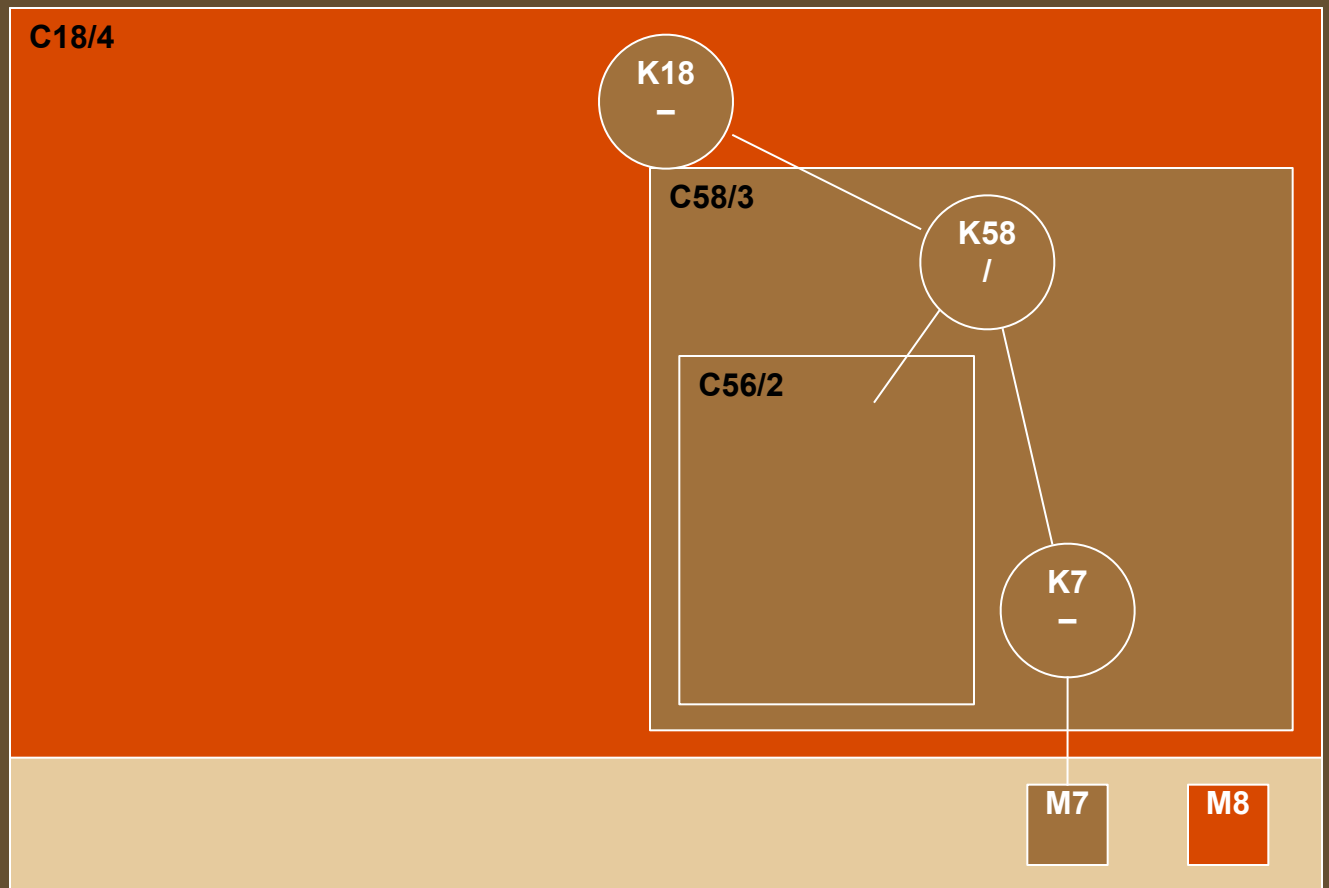
Member Joins

- Node cannot be added here since height increase is not allowed



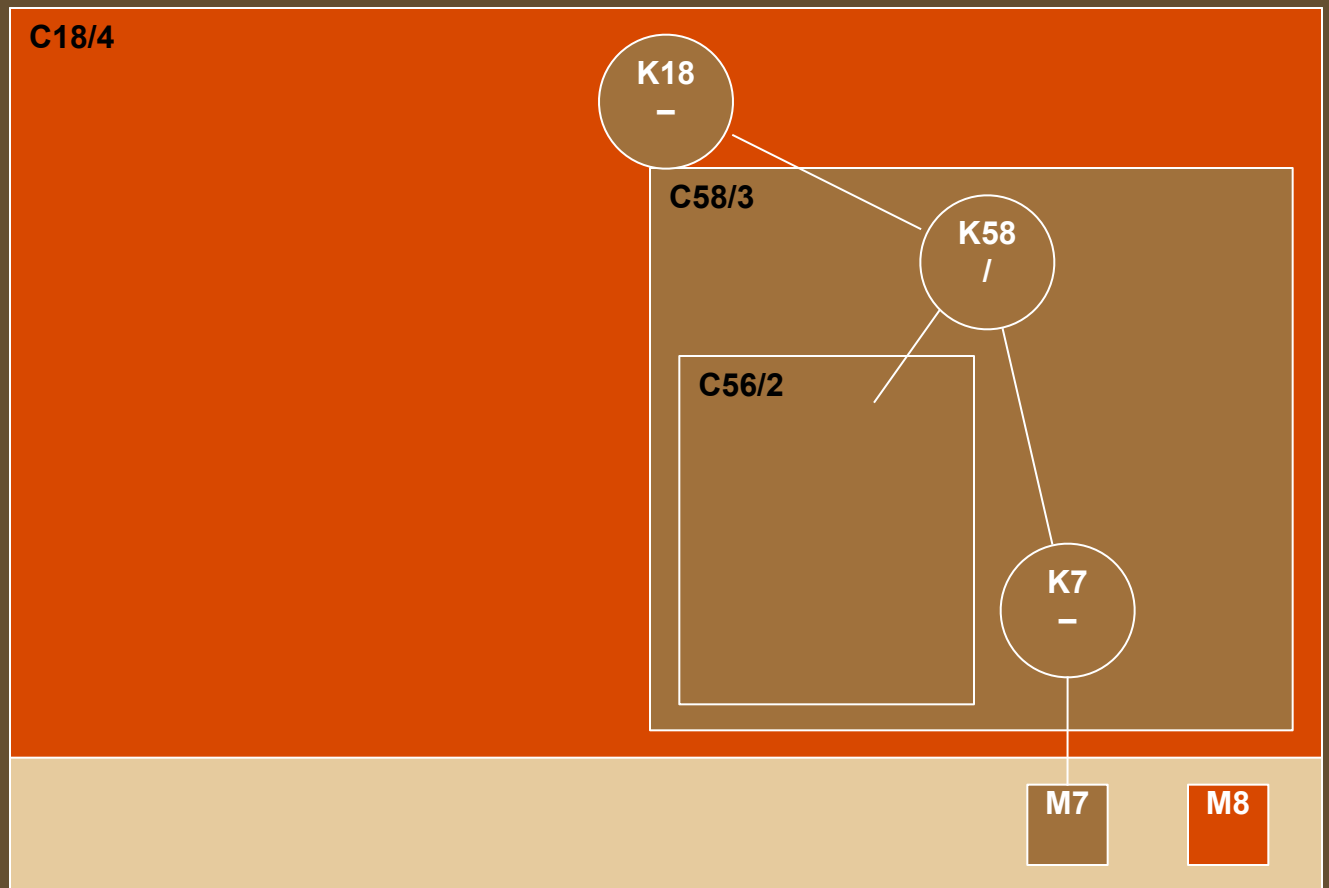
Member Joins

- Request is passed on to parent controller C58



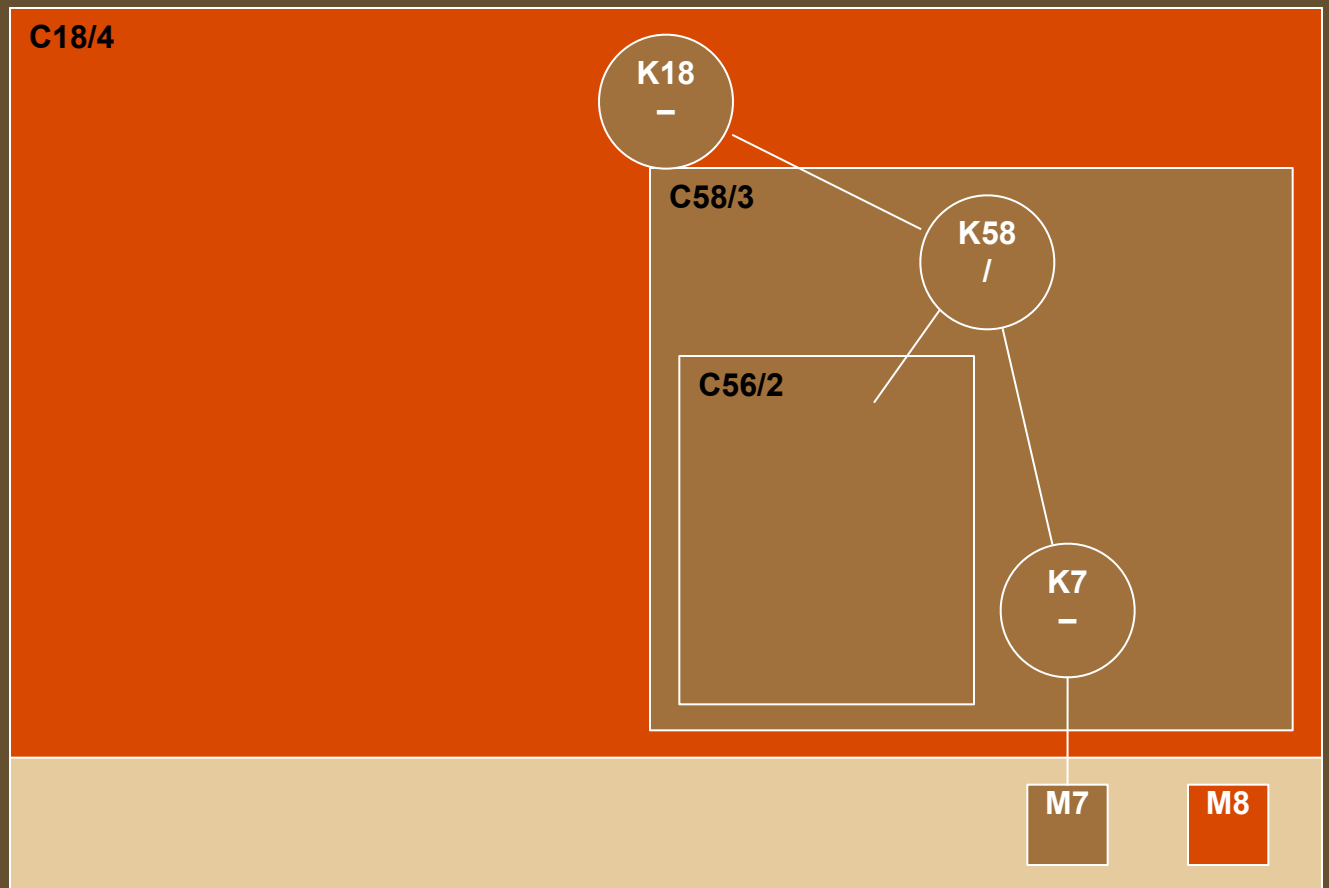
Member Joins

- Controller must add the new member on right side with height increase allowed



Member Joins

- Leaf node K7 must be split to accommodate for the new member



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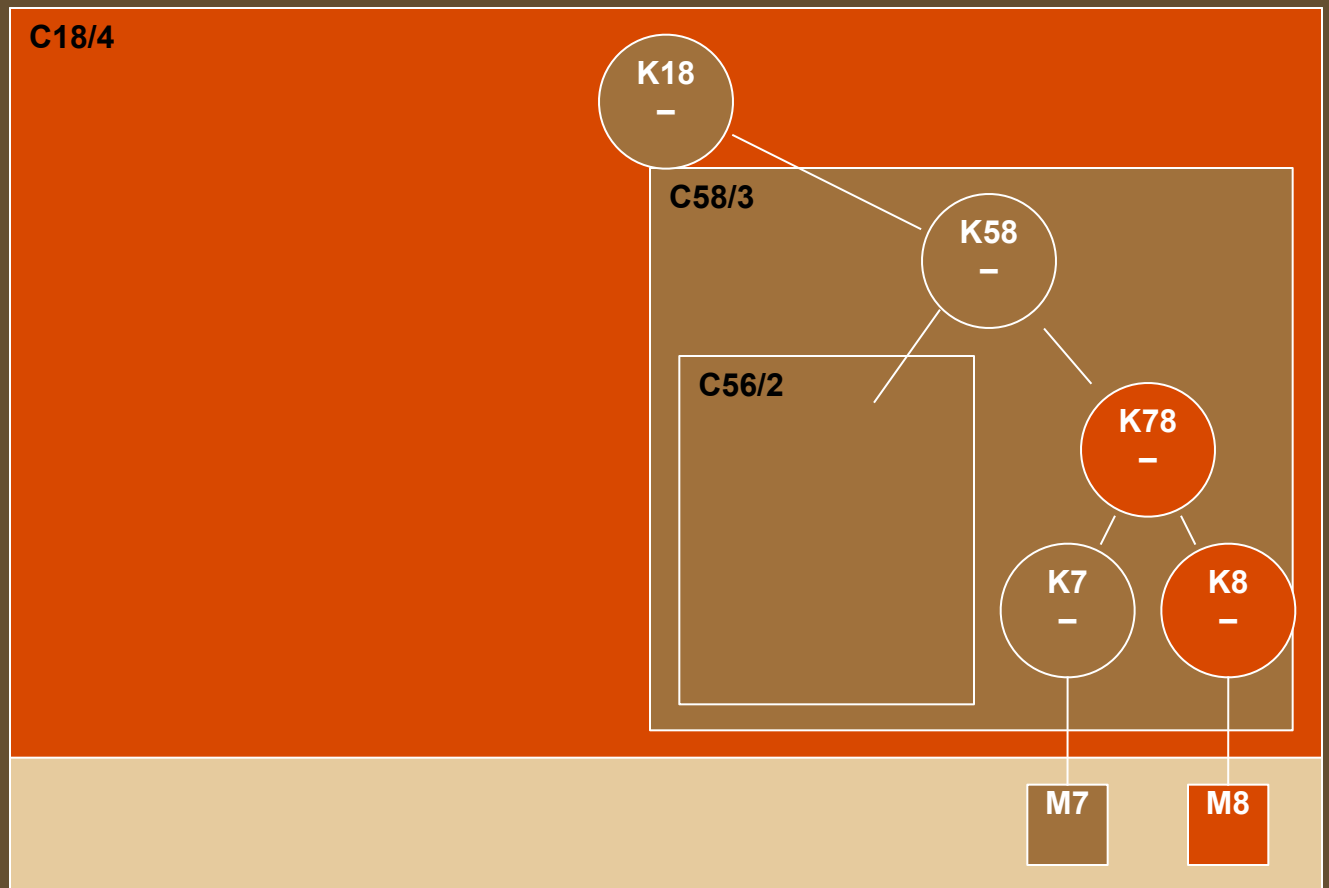
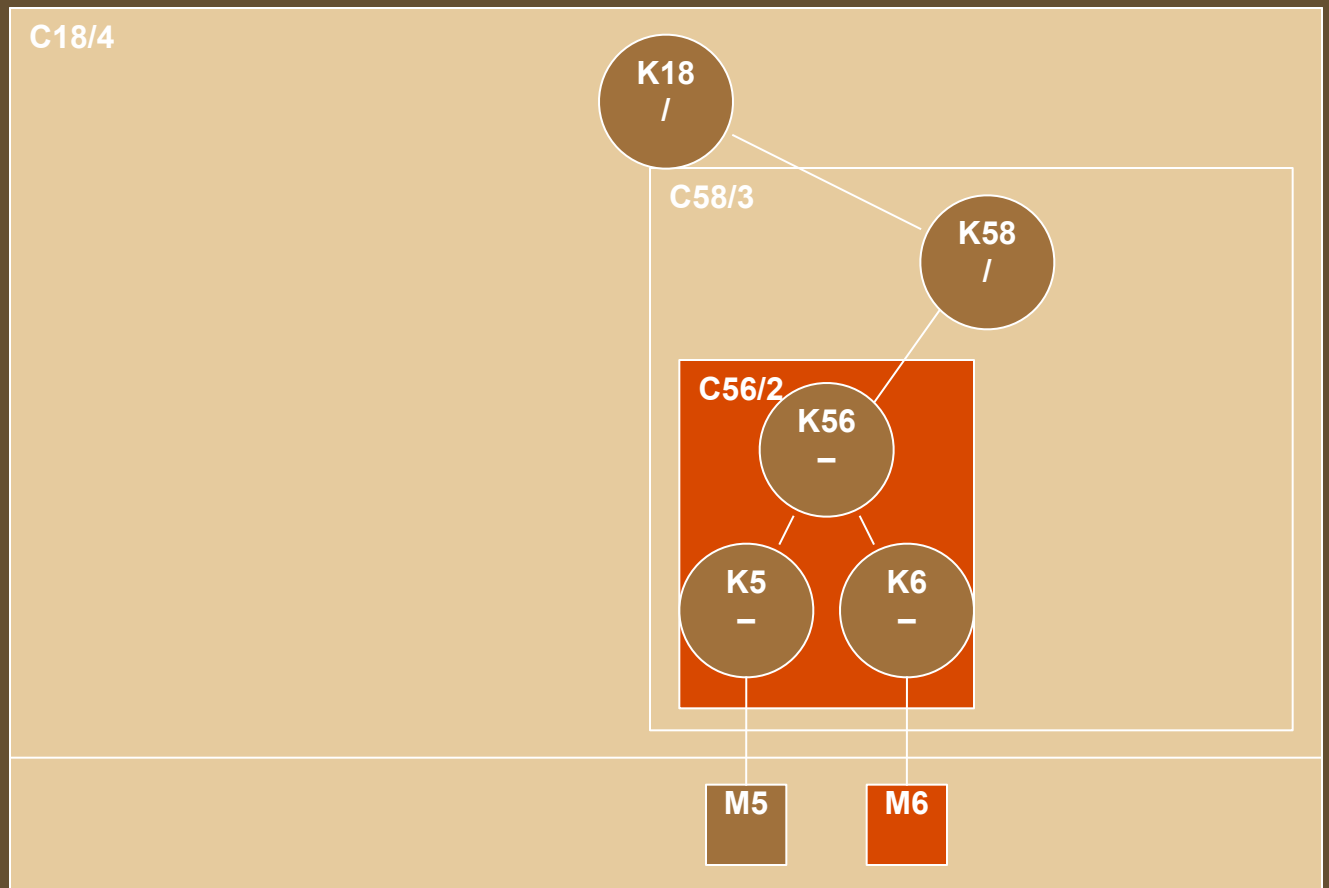


Member Joins

- To balance load the root controller forwards join requests to different controllers
- Height increase is only allowed when moving in a smaller sub-tree or when starting from root
- If insertion without height increase is impossible request is forwarded to parent controller
- Parent controller repeats the same algorithm except that it does not send the member back to the same controller

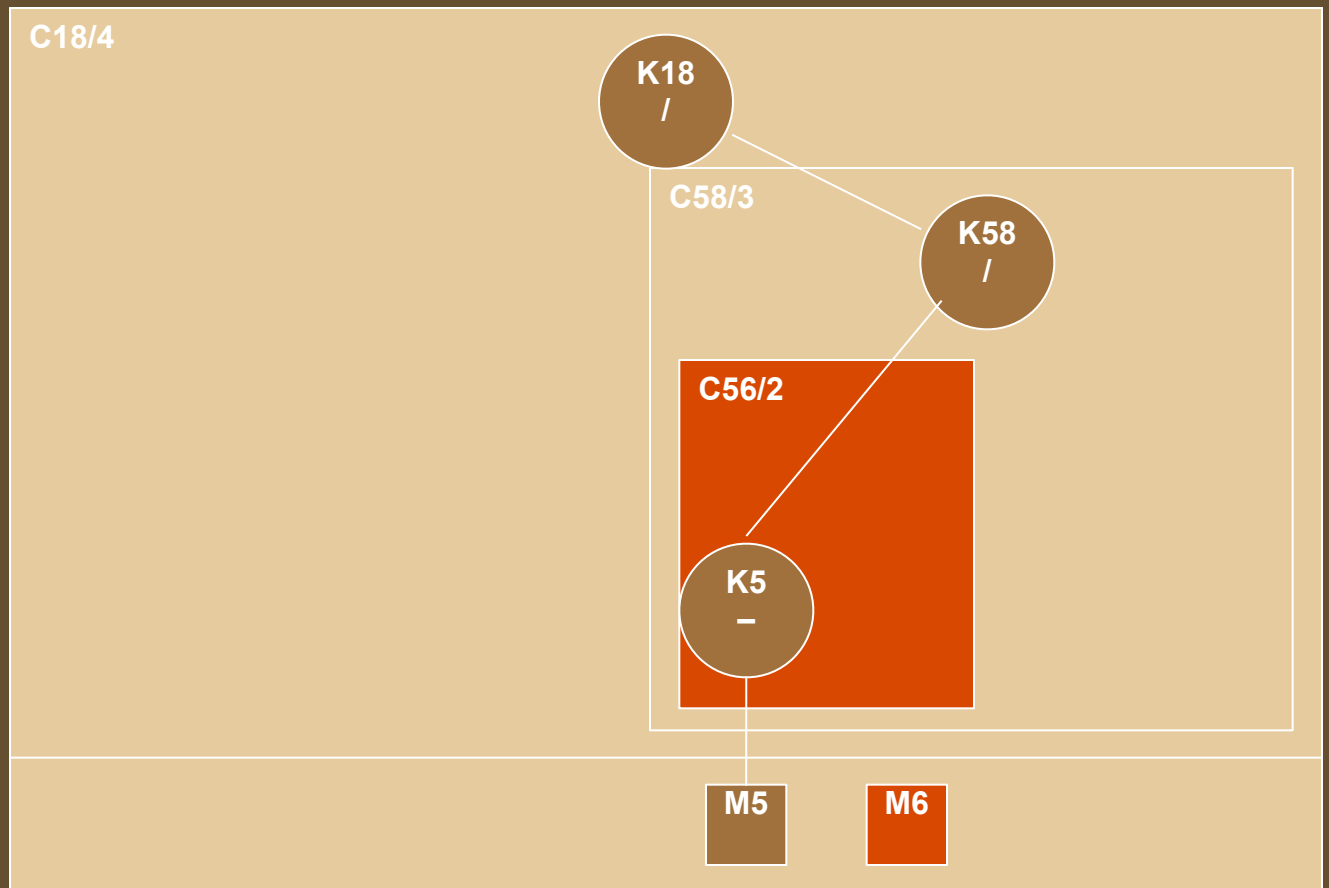
Member Leaves

- M6 wants to leave the group and informs its parent controller C56



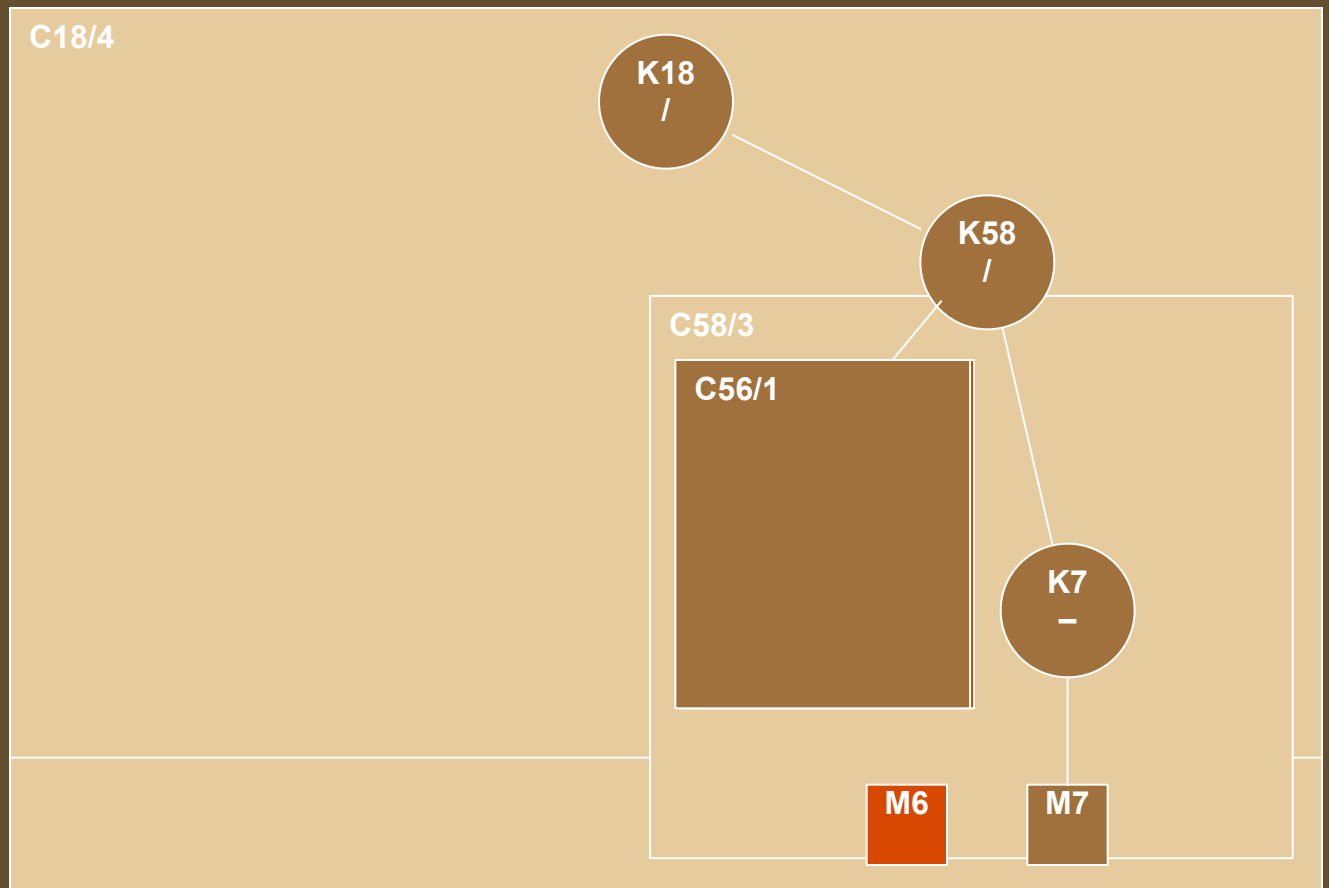
Member Leaves

- Controller merges nodes to remove M6 from the tree



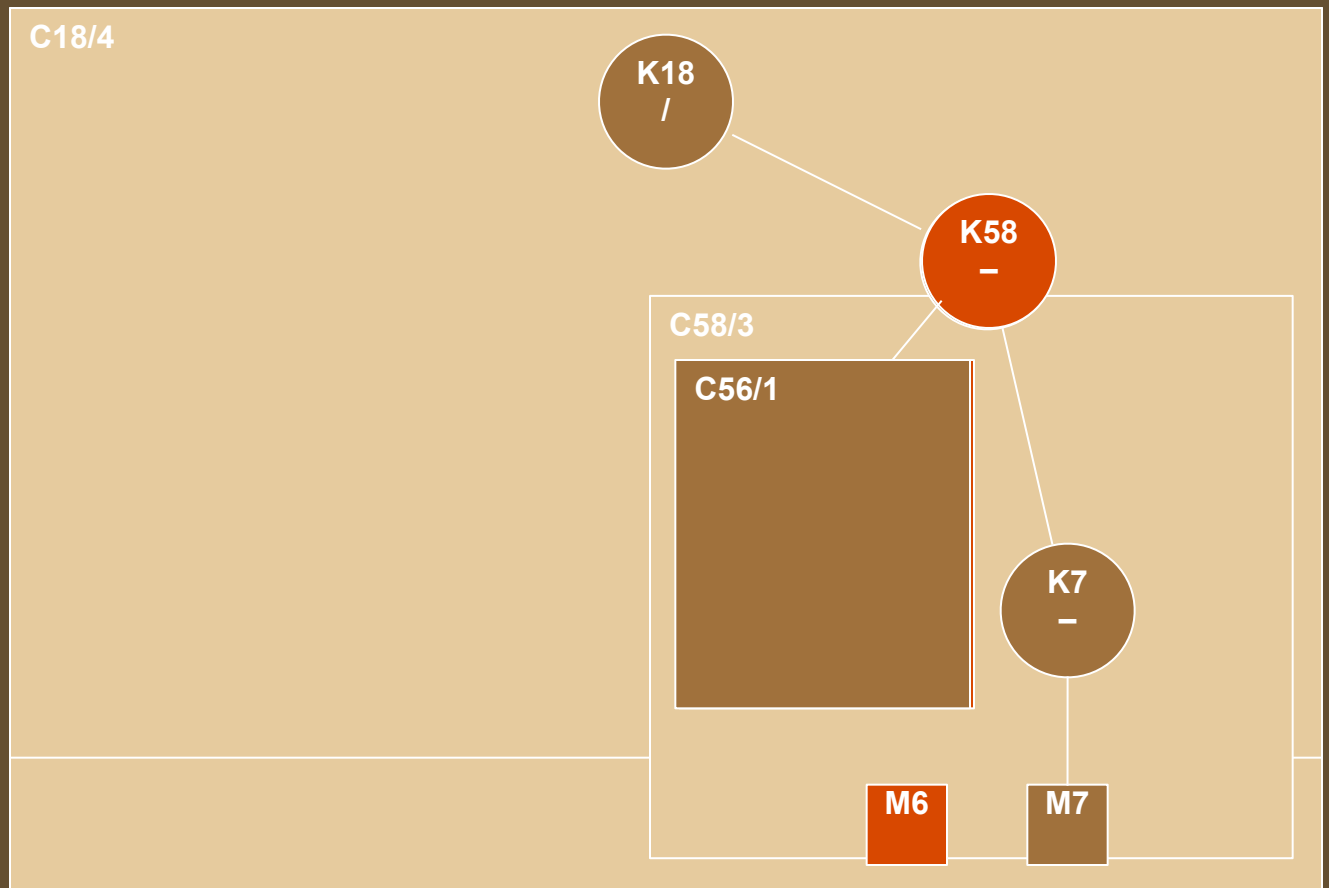
Member Leaves

- Sub controller height is changed so parent controller is informed



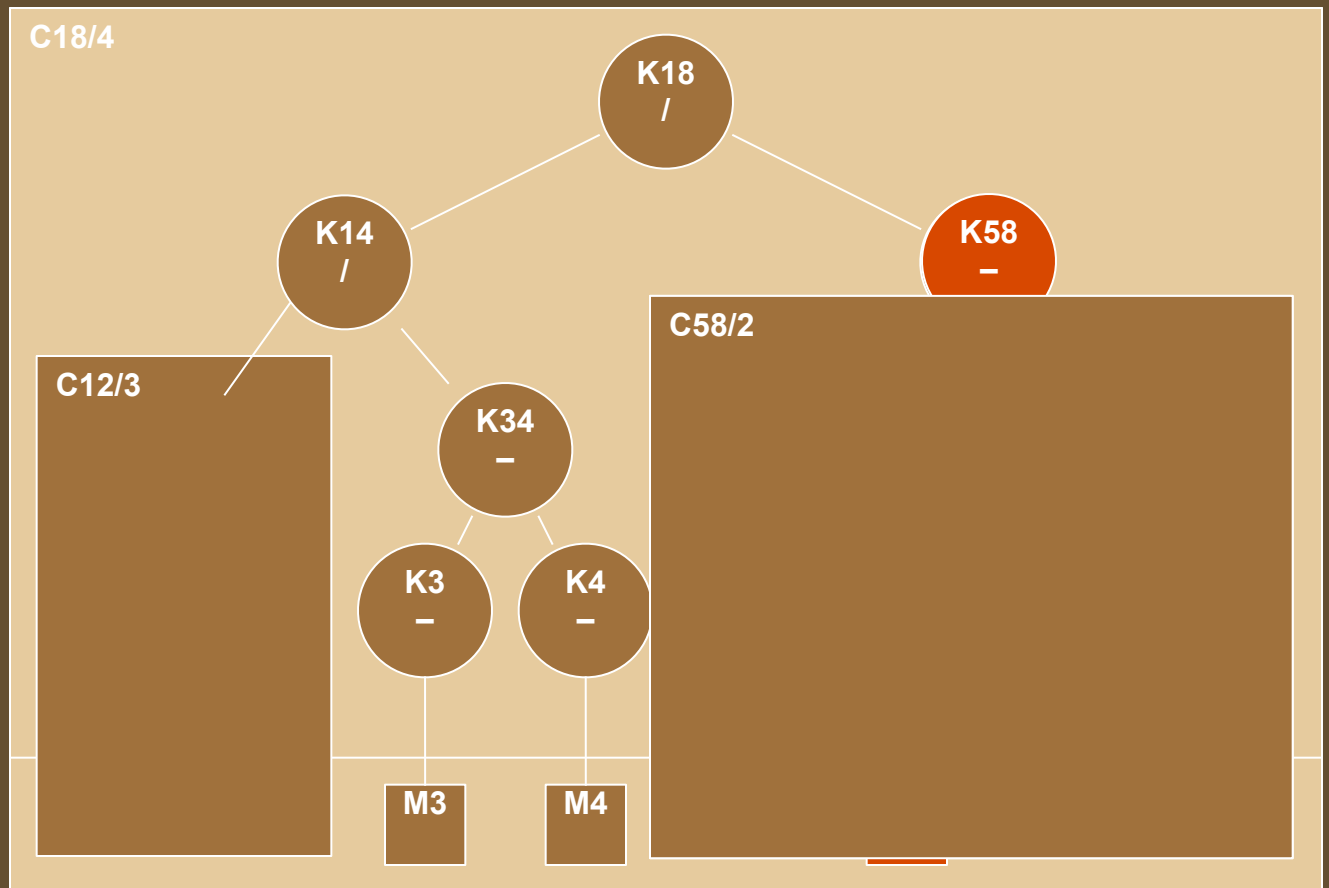
Member Leaves

- Parent adjusts the balance of its nodes



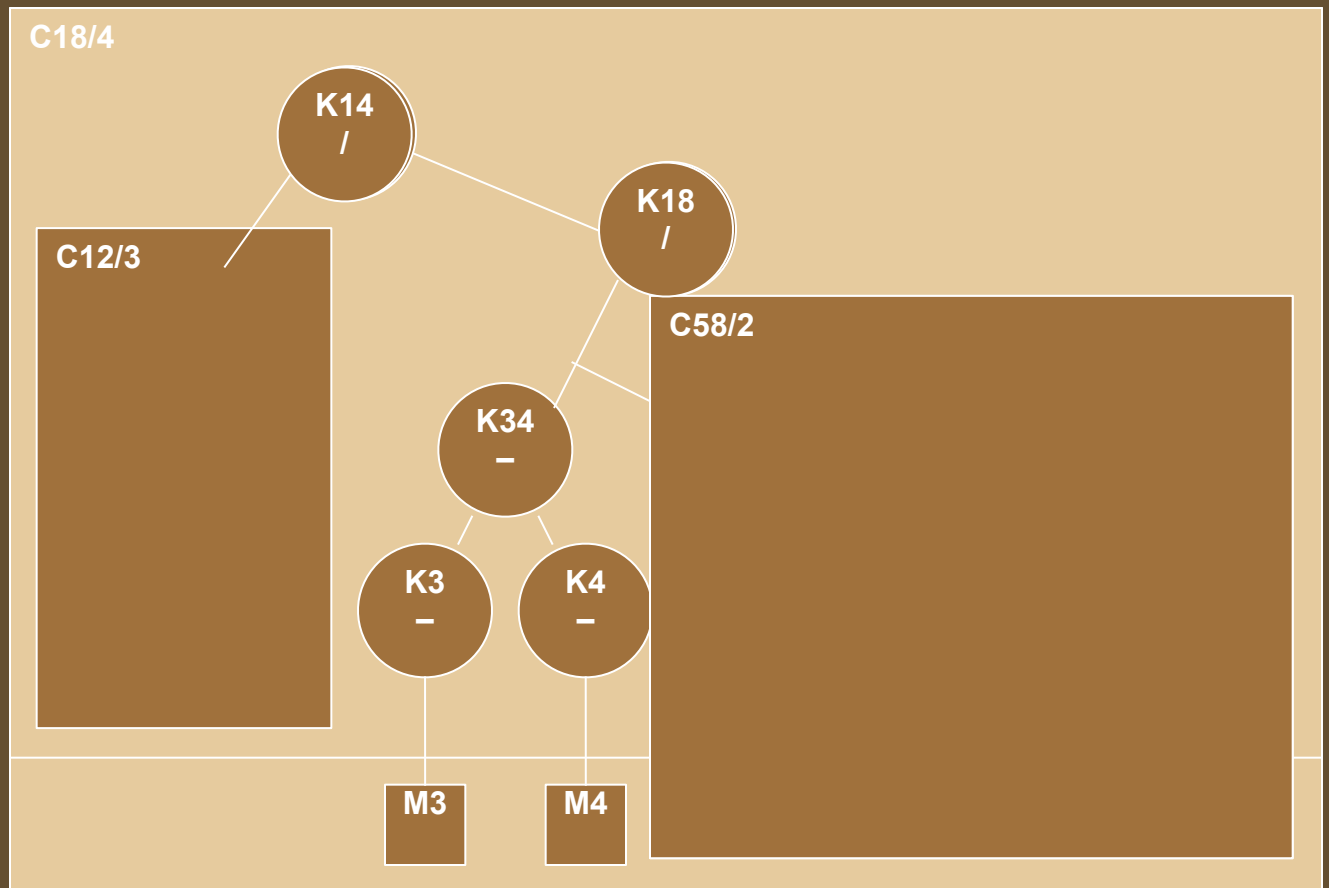
Member Leaves

- Height of controller is changed so the root controller is informed



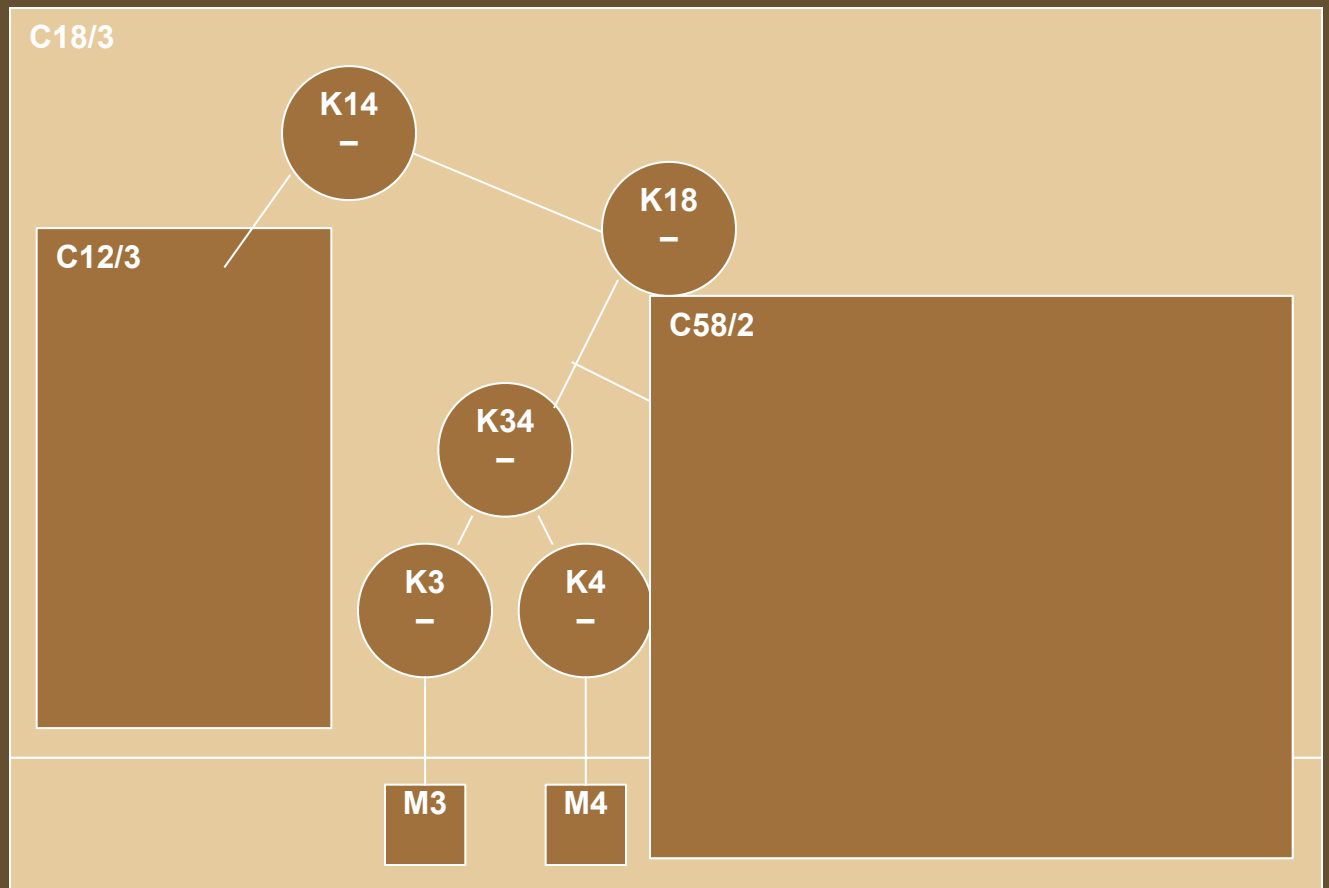
Member Leaves

- Smaller sub tree reduced in height so the root controller must undergo a rotation



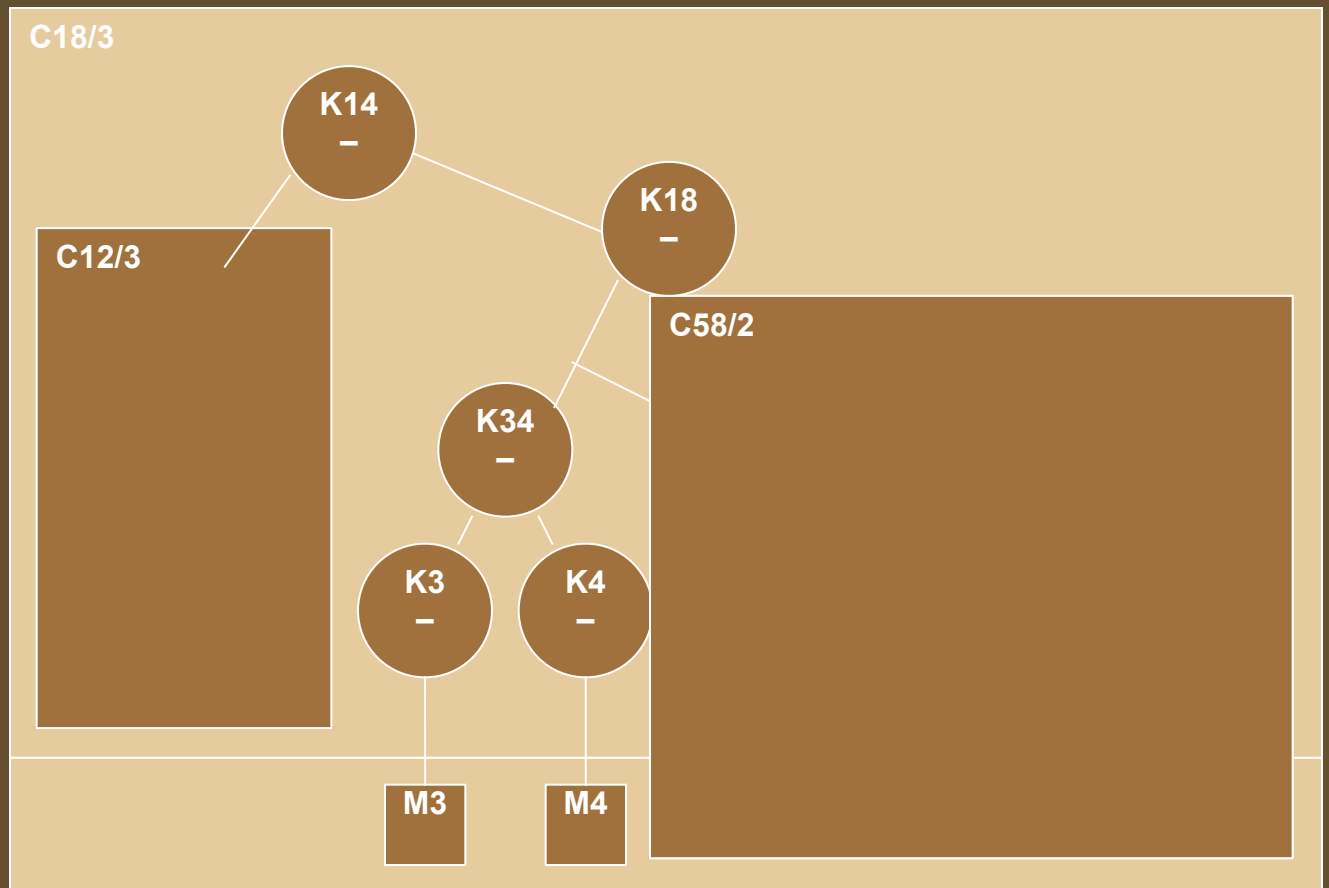
Member Leaves

- Balance of rotated nodes are adjusted



Member Leaves

- All keys on leaving member's path to the root are updated



Member Leaves

- Member informs parent controller
- Parent controller removes node from tree and adjusts nodes' balances
- If there is a difference of two in heights of sub trees a rotation is done
- If due to rotations height of total tree decreases the grandparent is informed which may itself need to go into rotations

Analysis

- Frequency of Rotations
- Analytic Comparison
- Conclusion

Frequency of Rotations

Group size	Rotations			
	Zero	One	Two	Three
10000	7692	2213	93	2
100000	77441	20535	2022	2
1000000	759008	230774	10142	76

One rotation causes 2 extra keys to be sent
0.24 rotations per leave or 0.48 keys per leave

Analytic Comparison

	LKH	Proposed LKH
Multicast message size for key Update	(2d-1)K	(2d-1+c +0.48)K
Storage at controller	(2n-1)K	(2n-1+C)K Distributed
Key update processing at Controller	(2d-1)E	(2d-1+C)E Distributed

d – depth of the tree
n – number of group members
c – number of controller in the path to the root
C – total number of controllers
K – key size
E – cost of encryption

Conclusion

- Key update increased from 2d-1 keys to 2d-1+c+0.48 keys
- However d is now guaranteed to be log n
- The overhead of balancing (0.48K) is less than overhead of height increase (2K)
- Storage and processing at controllers increases by factor of C keys but is distributed among all controllers

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