Lecture 7: Cellular Network

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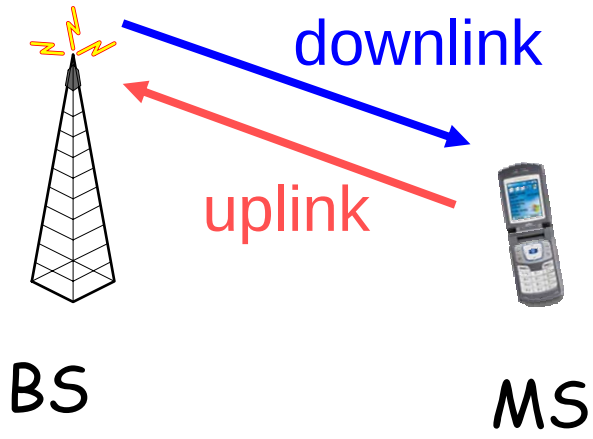
Announcement

- 11/30 midterm
- 11/23, 11/16 project proposal presentation
  - 2~3 people
  - 12 minutes
- 11/16, 11/9
  - Transport layer
  - Case study: multimedia over wireless
- Email me your group members by next Friday
  - hywei@cc.ee.ntu.edu.tw

Cellular Basics

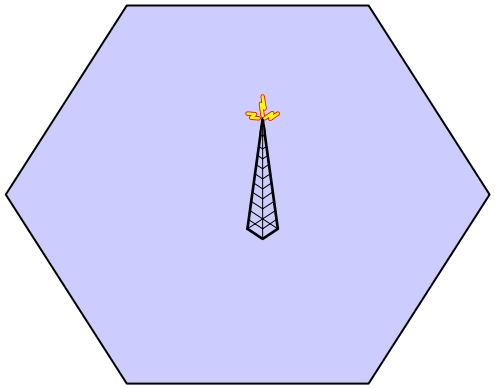
Terminologies: BS & MS

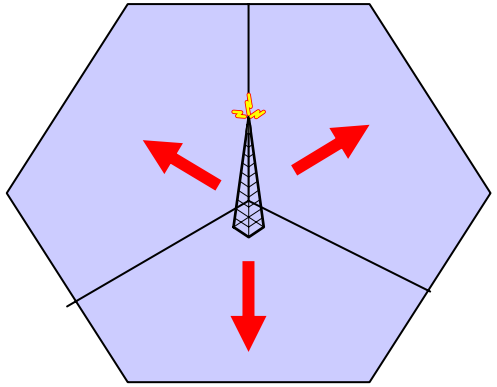
- Base station (BS)
  - Access point (AP)
- Mobile station (MS)
  - SS (Subscriber station)
  - MT (mobile terminal)
  - MN (mobile node)
- Downlink
  - Forward link
  - BS➔MS
- Uplink
  - Reverse link
  - MS➔BS



Terminologies: cell and sector

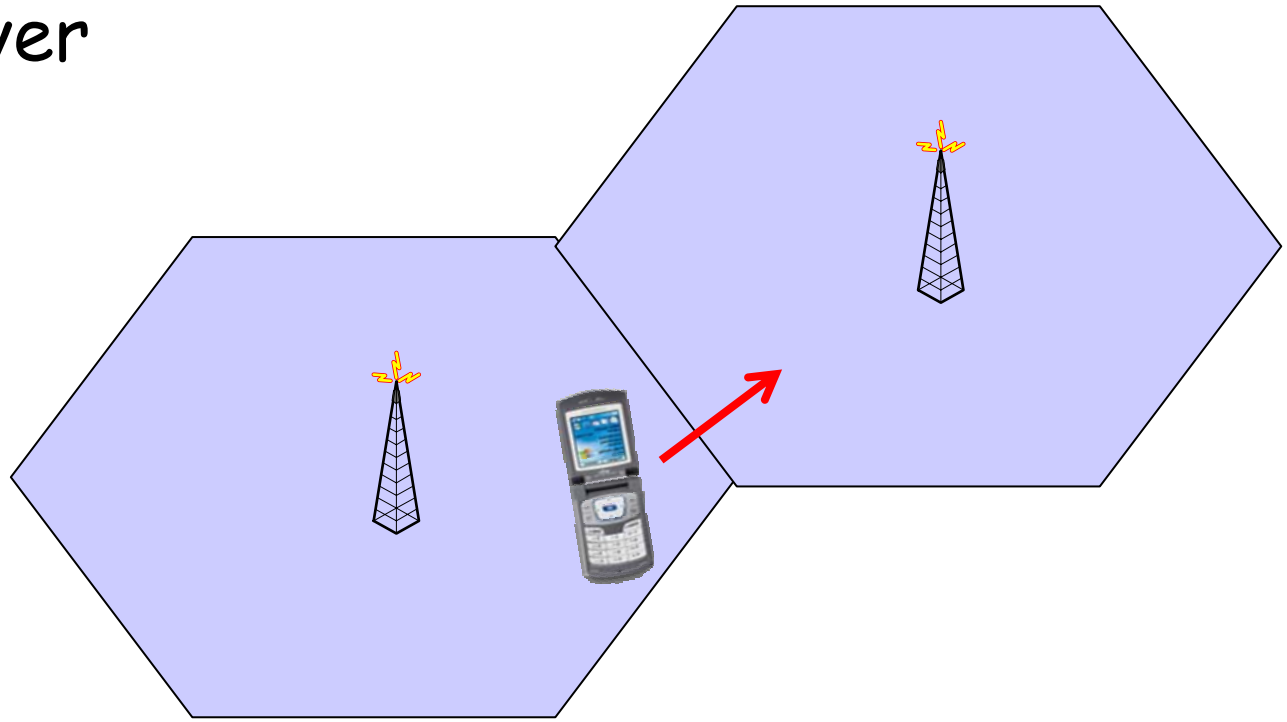
- Cell
  - Coverage area of a BS
- Sector
  - Partial area of a cell that is served by a directional antenna





Terminology: handoff

- Handoff
  - MS changes serving BS due to movement or radio channel variation
  - handover

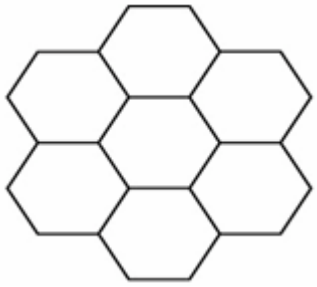


1G and 2G cellular systems

- 1st generation
  - AMPS
    - Analog
    - Analog FM modulation
    - FDMA
- 2nd generation
  - DAMPS(IS-54)
    - U.S.
    - Digital PSK modulation
    - FDM/TDMA
  - GSM
    - Europe, Asia
    - Digital PSK modulation
    - FDM/TDMA
  - IS-95 CDMA
    - U.S.
    - Digital PSK modulation
    - FDM/CDMA

Basic Cellular Concept

- "Cell"
  - Typically, cells are hexagonal
  - In practice, it depends on available cell sites and radio propagation conditions
- Spectrum reuse
  - Reuse the same EM spectrum in other geographical location
  - Frequency reuse factor



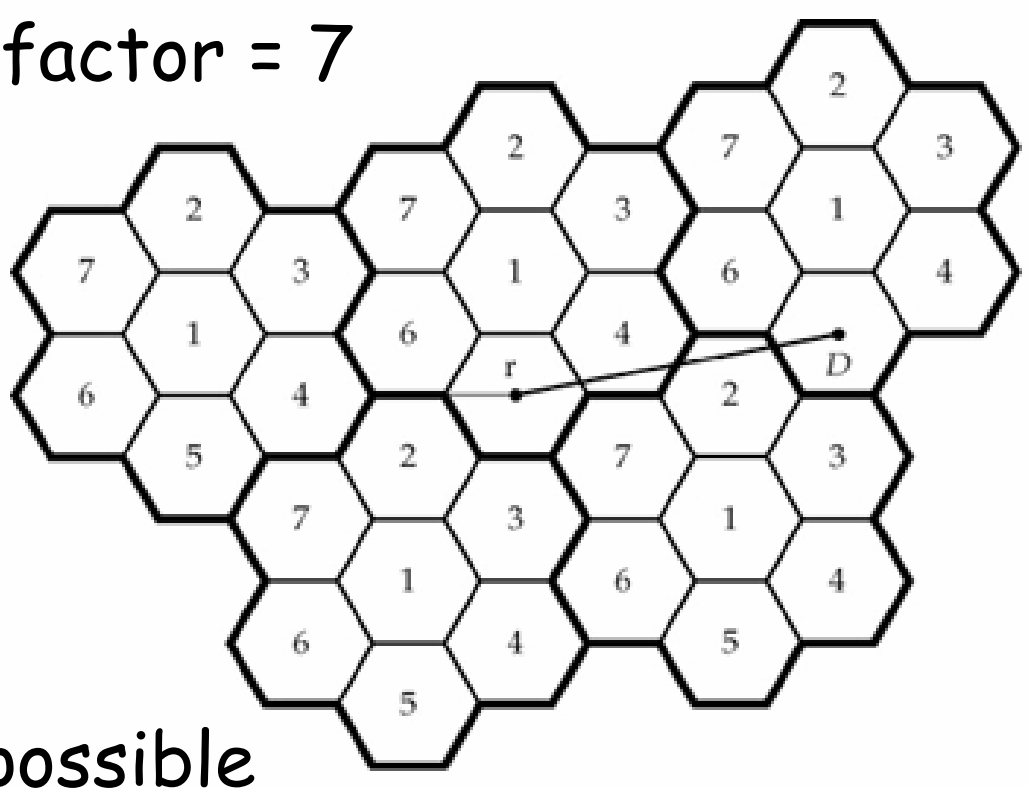
Frequency Reuse

- Cluster
  - A group of cells
- Frequency reuse factor
  - (Total # of channels in a cluster) / (Total # of channels in a cell)

TDMA/FDMA Spatial Reuse

A frequency reuse example

- Example
  - Frequency reuse factor = 7
  - Cluster size =7



- Question
  - What are other possible frequency reuse patterns?

Cluster

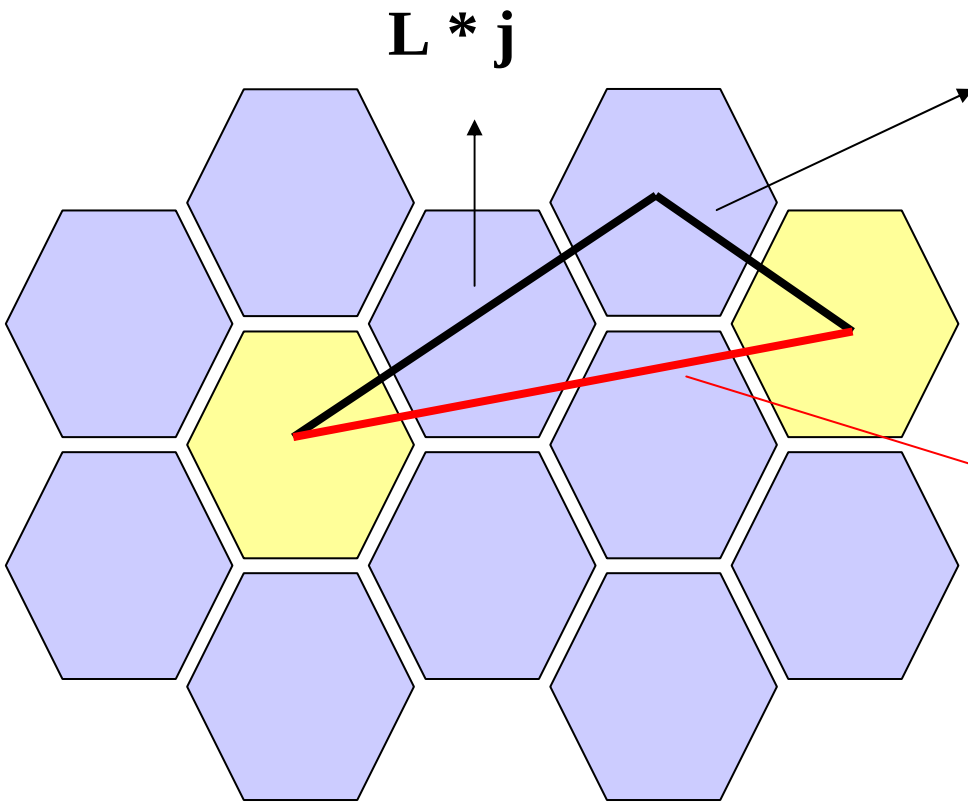
- The hexagon is an ideal choice for macrocellular coverage areas, because it closely approximates a circle and offers a wide range of tessellating reuse cluster sizes.
- A cluster of size N can be constructed if,
  - $N = i^2 + ij + j^2$.
  - i,j are positive integer
- Allowable cluster sizes are
  - N = 1,3,4,7,9,12,…

Determine frequency reuse pattern

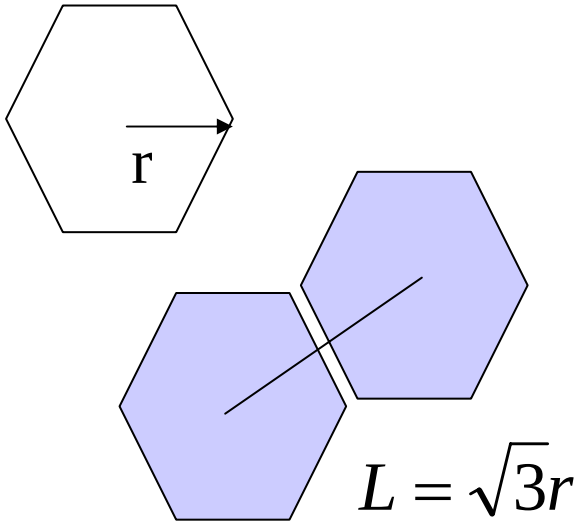
- Co-channel interference [CCI]
  - one of the major factors that limits cellular system capacity
  - CCI arises when the same carrier frequency is used in different cells.
- Determine frequency reuse factor
  - Propagation model
  - Sensitivity to CCI

Reuse distance

- Notations
  - D :Reuse distance
    - Distance to cell using the same frequency
  - r : Cell radius
  - N : Frequency reuse factor
- Relationship between D and r
  - D/r=(3N)^0.5
  - $N = i^2 + ij + j^2$
- Proof?



In this case: j=2, i=1



$$D^2 = (L \cdot i)^2 + (L \cdot j)^2 - 2(L \cdot i)(L \cdot j)\cos(2\pi/3)$$

$$D^2 = L^2 \cdot i^2 + L^2 \cdot j^2 - 2L^2 \cdot i \cdot j \cdot (-0.5)$$

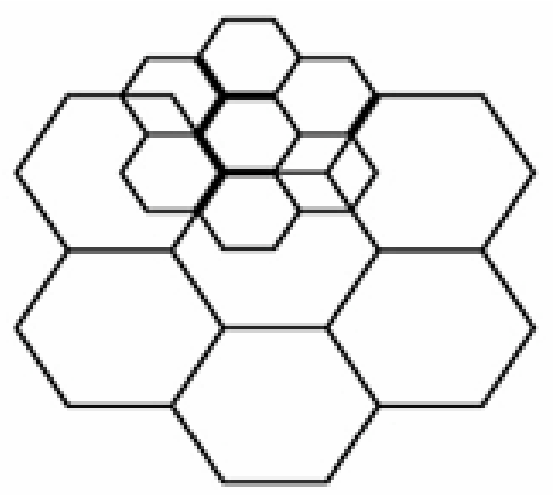
$$D^2 = L^2(i^2 + j^2 + ij)$$

$$D/r = \sqrt{3(i^2 + j^2 + ij)} = \sqrt{3N}$$

Compute D based on "law of cosine"

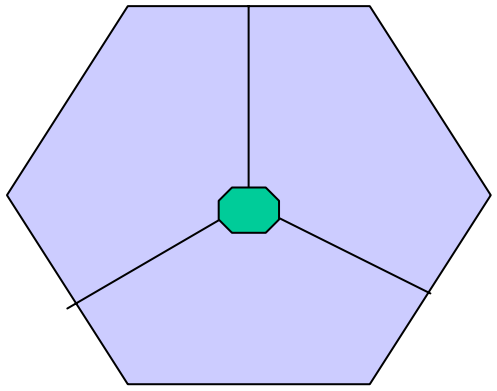
Cell splitting

- Smaller cells have greater system capacity
  - Better spatial reuse
- As traffic load grows, larger cells could split into smaller cells



Sectors

- Use directional antenna reduces CCI
  - Why? Think about it!
- 1 base station could apply several directional antennas to form several sectors
- 3-sector cell



Forward link and reverse link

- Forward link
  - Also called downlink
  - BS→MS
- Reverse link
  - Also called uplink
  - MS→BS
- How forward link and reverse link are separated?
  - FDD (more often)
    - Frequency Division Duplex
  - TDD
    - Time Division Duplex
    - Why is it more difficult to engineer a TDD system?

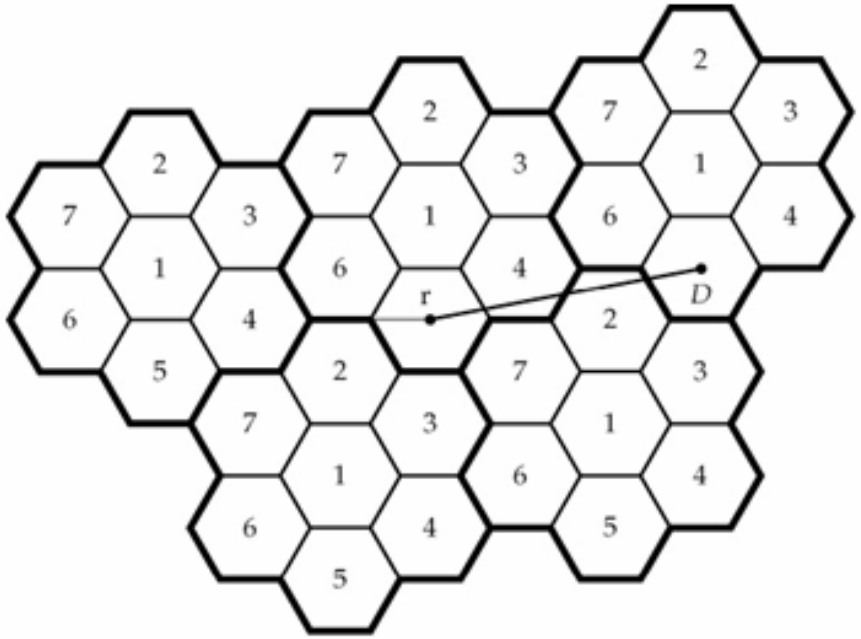
More about cellular

Cell size & FRF

- Cell size should be proportional to 1/(subscriber density)
- Co-channel interference is proportional to
  - 1/D
  - r
  - 1/N^0.5
  - Path-loss model
- Total system capacity is proportional to
  - 1/N
    - N : Frequency reuse factor

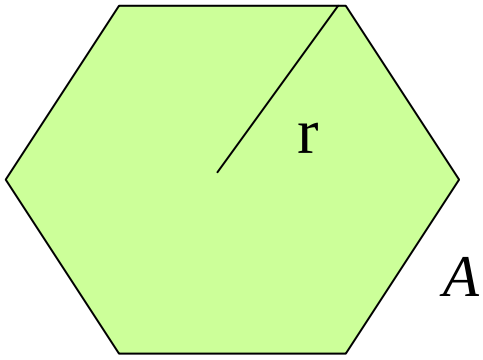
Example: N=7

- Frequency reuse factor N=7
  - $N = i^2 + ij + j^2$
  - (i,j)=(1,2) or (2,1)
- Other commonly used patterns
  - N=3
    - (1,1)
  - N=4
    - (2,0); (0,2)
- N=1 is possible
  - CDMA



Compute total system capacity

- Example 11-1
  - Total coverage area = 100 mile^2 = 262.4 km^2
  - Total 1000 duplex channels
  - Cell radius = 1km
  - N=4 or N=7
- What's the total system capacity for N=4 and N=7?

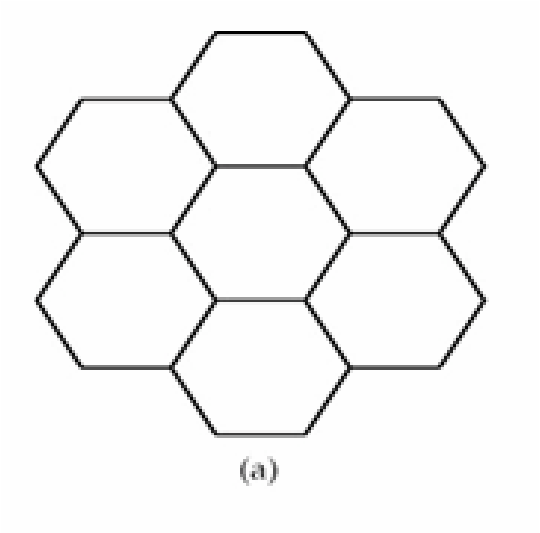


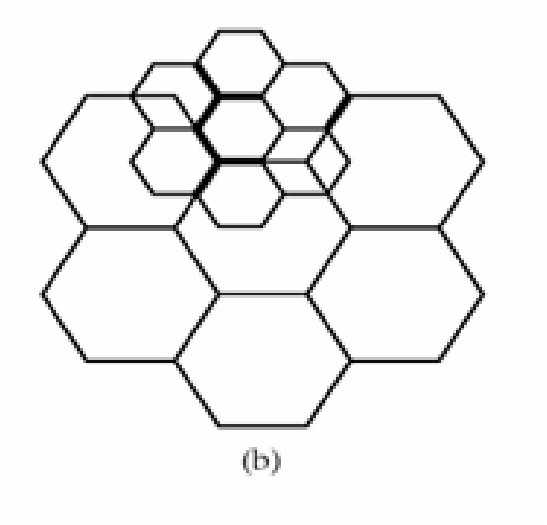
$$A = \frac{3\sqrt{3}}{2} r^2 = 2.6r^2$$

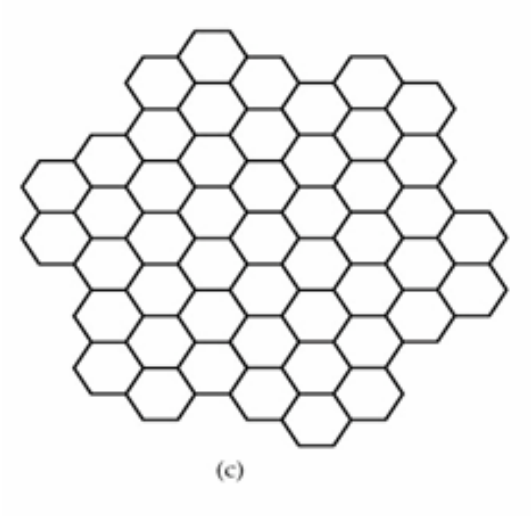
Compute total system capacity

- # of cells = 262.4/2.6=100 cells
- # of usable duplex channels/cell
  - S=(# of channels)/(reuse factor)
  - S_4=1000/4=250
  - S_7=1000/7=142
- Total system capacity (# of users could be accommodated simultaneously)
  - C=S*(# of cells)
  - C_4=250*100=25000
  - C_7=142*100=14200

Evolving deployment







Early stage Intermediate stage Late stage

- Multiple stages of deployment
- Deployment evolves with subscriber growth

Practical deployment issues

- Location to setup antenna
  - Antenna towers are expensive
  - Local people do not like BSs
    - Antenna/BS does not look like antenna/BS
- Antenna
  - Omni-directional
  - Directional antenna

Wireless QoS

- Quality of Service (QoS)
  - Achieving satisfactory wireless QoS is an important design objective
- Quality measures
  - Channel availability (wireless network is available when users need it)
    - Blocking probability
    - Dropping probability
  - Coverage: probability of receiving adequate signal level at different locations
  - Transmission quality: fidelity/quality of received signals
    - BER
    - FER
- Application-dependent
  - Voice
  - Data
  - Multimedia

Wireless QoS

- Admission control
  - Blocking
  - Poor reception quality
- Co-channels
  - Frequency reuse factor
  - Cell planning
    - Frequency planning

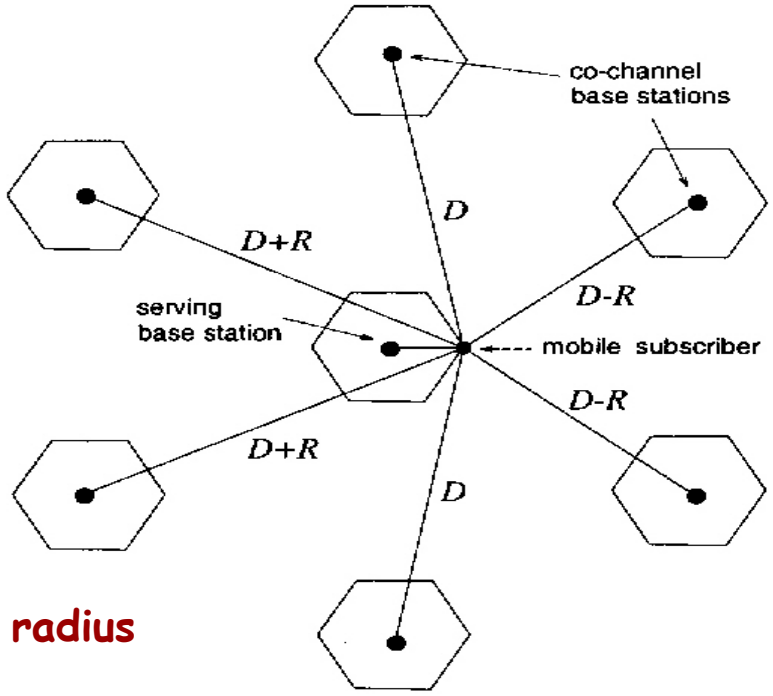
Worst-Case CCI on the Forward Channel

- Co channel interference [CCI] is one of the prime limitations on system capacity. We use the propagation model to calculate CCI.

- There are six first-tier, co-channel BSs, two each at (approximate) distances of D-R, D, and R+D and the worst case (average) Carrier-to-(Co-Channel) Interference [CCI] is

$$\Lambda = \frac{1}{2}\frac{R^{-\beta}}{(D-R)^{-\beta} + D^{-\beta} + (D+R)^{-\beta}}$$

Worst case CCI on the forward channel

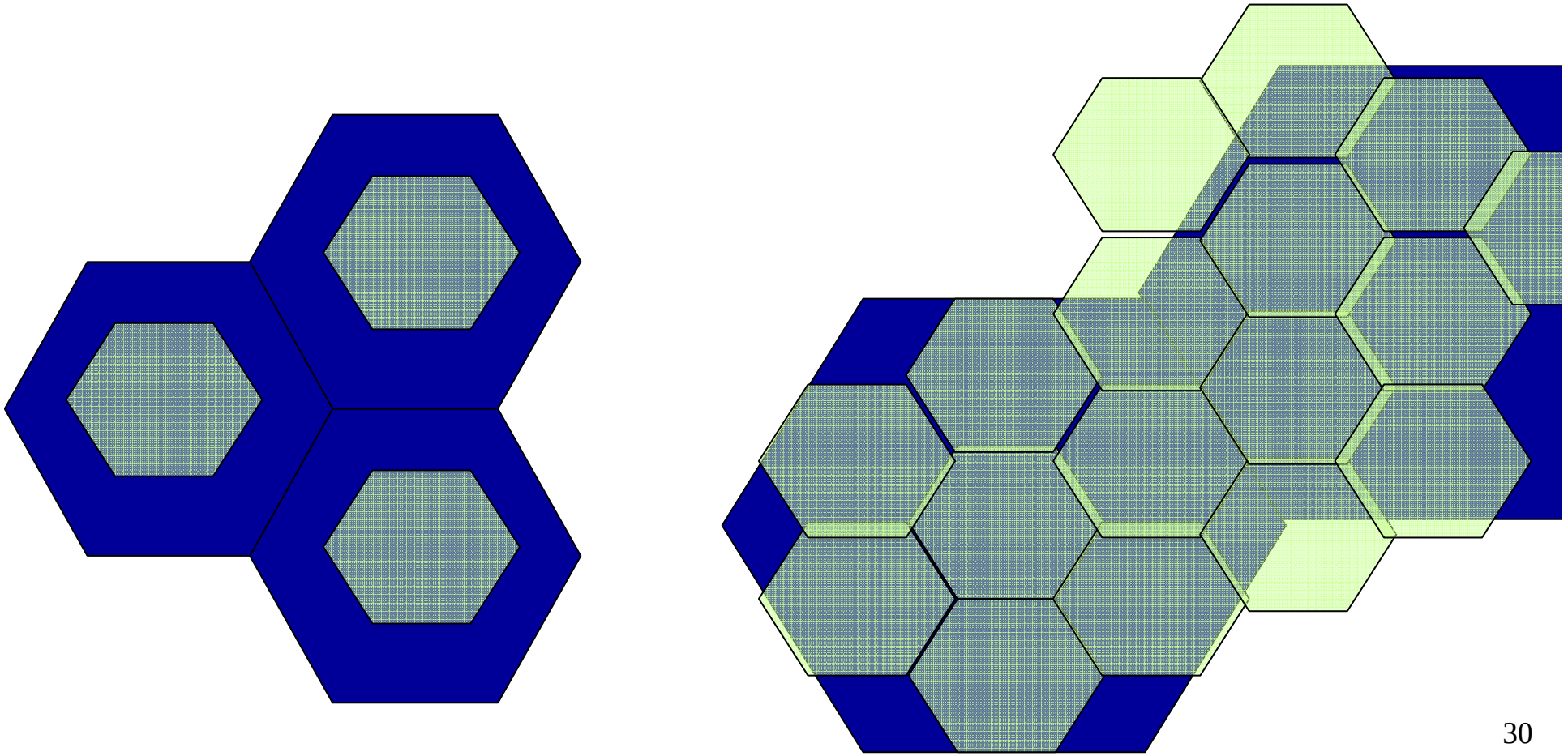


R= cell radius

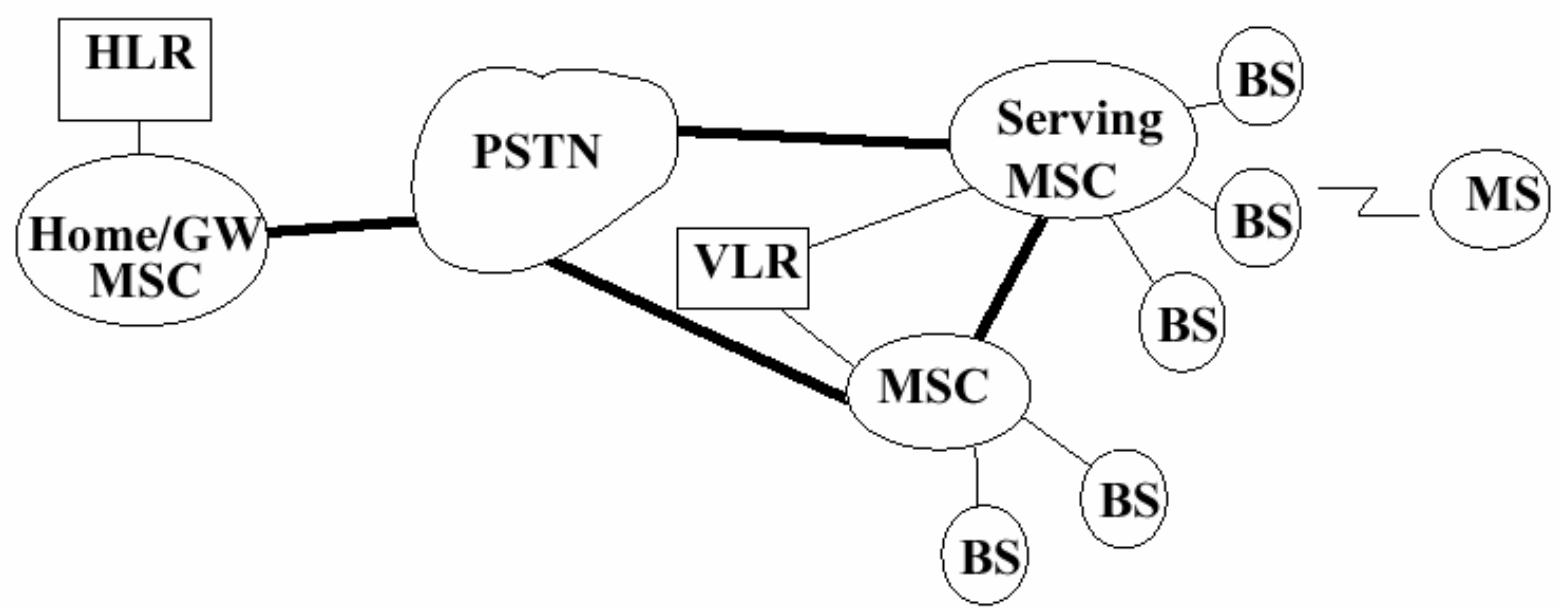
Overlay

- Dual-mode or dual-frequency phones
  - Overlay different wireless access technologies
    - Different technologies
    - Same technology operating in different bands
- Increase system capacity
  - Reduce blocking
- Example:
  - GSM 900/1800
  - TDMA+CDMA

Overlaid cells



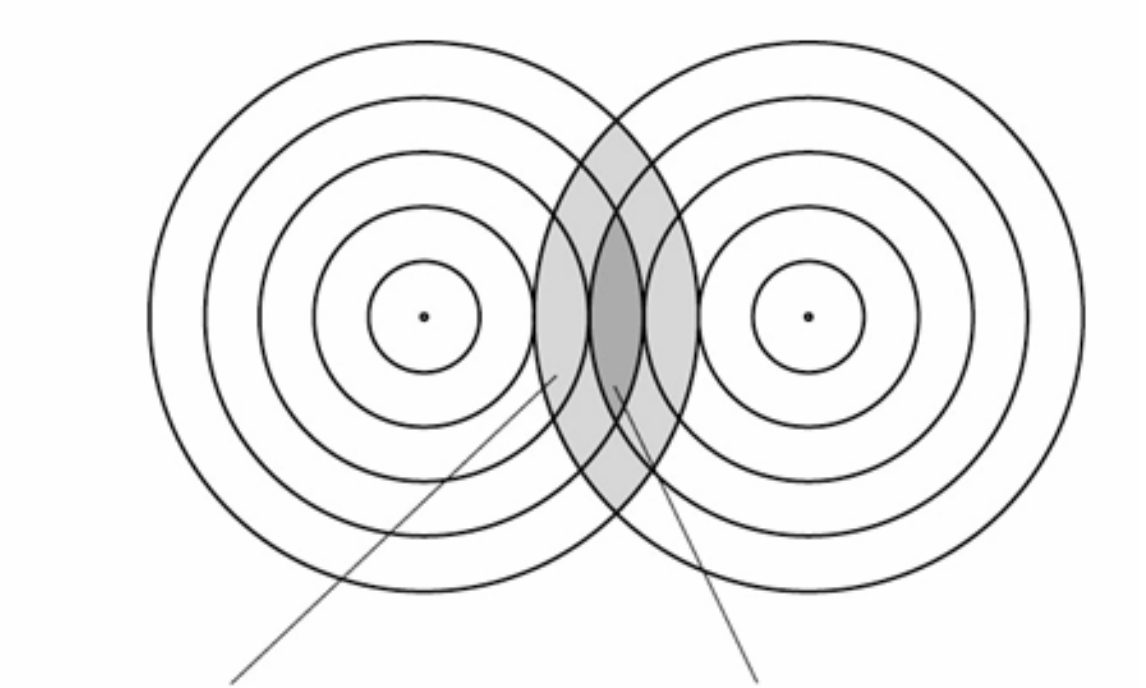
Basic Cellular Network Architecture



- Home/ Gateway MSC: receives incoming calls for mobiles
  - if using a home MSC, it is permanently assigned
- Serving MSC: is assigned based on location of MS
- HLR: permanent repository for service profiles, pointer to VLR
- VLR: temporary repository for profile information and pointer to serving MSC

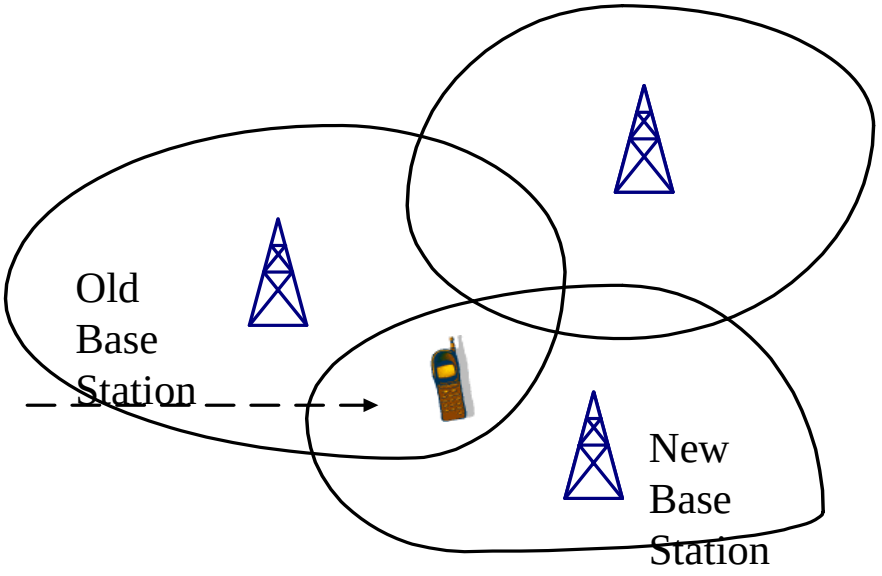
Handoff

- Handoff threshold: typically, -90~-100 dBm (1~10uW)
- Need to prevent from "ping-pong" effect



Handoff Management

- the new BS before the link between the old BS and the MS becomes unusable
- There are three primary issues that need to be considered for handoff management
  - Handoff detection
  - Channel assignment
  - Radio link transfer



Cell Crossing Rate: Fluid Flow Mobility Model [for Handoffs]

- Model Assumptions
  - Mobile nodes move at constant rate v
  - Mobile nodes move in random direction, which is uniformly-distributed over [0,2 π]
  - Mobile nodes are uniformly-distributed in the cells.
- The cell crossing rate is given by

$$r_C = \frac{\rho v l}{\pi}$$

r_C : cell boundary cross rate $(1/\text{sec})$

ρ : active mobile node density $(1/m^2)$

v : mobile velocity (m/sec)

l : cell perimeter (m)

Handoff Modes

- Handoff algorithms can be characterized into forward and backward types
  - **Backward handoff**
    - Initiate the handoff process through the serving BS
    - Access to the new channel is not made until the control entity of the new channel has confirmed the allocation of resources.
    - Advantage : signaling information is through an existing radio link
      - The establishment of a new signaling channel is not required during the initial stages of the handoff process.
    - Disadvantage: may fail in conditions where the link quality with the serving BS is rapidly deteriorating.
    - Used in GSM and most TDMA systems.
  - **Forward handoff**
    - initiate the handoff process via a channel to the target BS without relying on the "old" channel during the initial phase of the handoff.
    - Advantage is a faster handoff
    - Disadvantage is a reduction in handoff reliability
    - Used in DECT
- Handoffs can also be either **hard** or **soft** handoffs

Link Quality Monitoring

- To initiate a handoff, two issues must be considered
  - Who initiates the handoff process?
  - How is the need for the handoff detected?
- Various parameters for link quality evaluation
  - Bit error rate [BER]
  - Carrier-to-interference ratio [CIR]
  - Distance
  - Traffic load
  - Signal strength
- Temporal averaging of the received carrier plus interference [C+I]
  - Advantages
    - Simplicity
    - Good performance in macrocellular systems.
  - Disadvantages
    - Efficient systems are interference [CCI] limited(a good C+I does r necessarily imply a large C/I)

3 Types of Handoff Algorithms

- **Network Controlled Handoff [NCHO]:**
  - Link quality is only monitored by the serving BS and the surrounding BSs.
  - The handoff decision is made under the centralized control of a mobile telephone switch
- **Mobile Assisted Handoff [MAHO]: Network Control with MS assisting**
  - Both the serving BS and MS measure link quality
  - Link quality measurements of the alternate BSs are only obtained by the MSs
  - The MS periodically relays the link quality measurements back to the serving BS
- **Mobile Controlled Handoff [MCHO]:**
  - link quality is measured by both BS and the MS.
  - Like MAHO, the measurements of link quality for alternate BSs are done at the MS, and both inter and intracell handoffs are supported
  - Unlike MAHO, the link measurements at the serving BS are relayed to the MS, and the handoff decision is made by the MS.

Link Quality Measurement and Handoff Initiation

- When a new call arrives, the MS must be connected to a suitable BS.
- Also, when a MS traverses a cell boundary → **intercell handoff**
  - Sometimes an intracell handoff is desirable when the link with the serving BSs is affected by excessive interference

- The handoff process consists of two stages
  - Link quality evaluation and handoff initiation
  - Allocation of radio and network resources
- Cellular systems with smaller cell sizes require faster and more reliable link quality evaluation and handoff algorithms
  - The handoff rate increases with only the square root of the call density in macrocells, but linearly with the call density in microcells.
  - Since the MS has a certain probability of handoff failure, handoff algorithms must become more robust and reliable as the cell size decreases

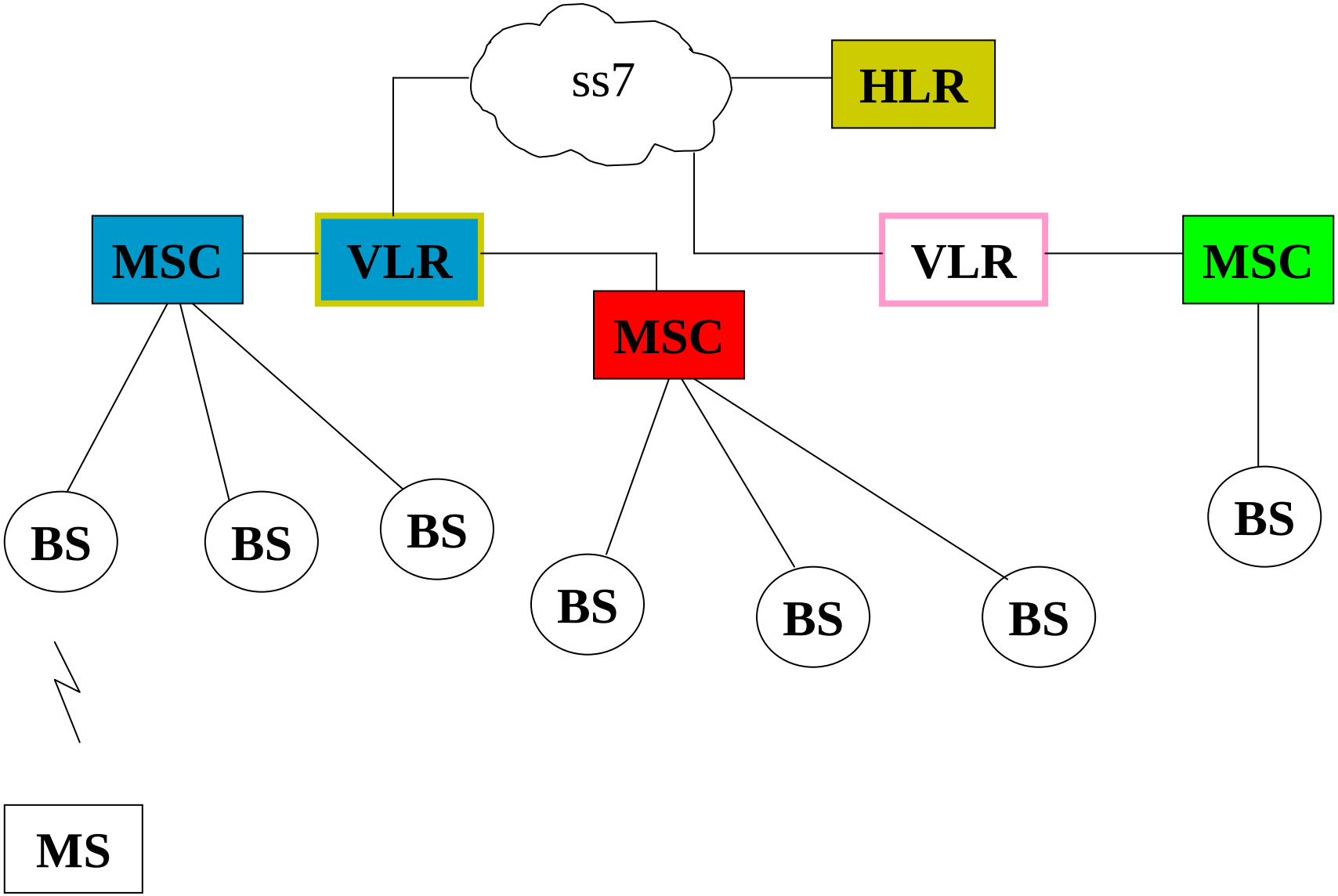
Handoff Failures

- In the link transfer procedure, there are several reasons why handoff failures occur:
  - No channel is available on the selected BS
  - Handoff is denied by the network for reasons such as lack of resources [e.g., the MS has exceeded some limit on the number of handoffs that my be attempted in a period of time].
  - It takes the network too long to set up the handoff after it has been initiated.
  - The target links fails in some way during the execution of the handoff
- The effect of network response time on the call completion probability can be significant; especially in the following cases
  - small offered load
  - mobile residence time distribution at a cell has a small variance

Channel Assignment

- Goals:
  - Service quality
  - Implementation complexity of the channel assignment algorithm
  - Number of database lookups
  - Spectrum utilization
- Handoff requests and initial access attempts compete for radio resources.
  - At a busy BS, call attempts that fail because there are no available channels are called *blocked calls*.
  - Handoff requests for existing calls that must turned down because there are no available channels are called *forced terminations*.
  - In general, *forced terminations* are less desirable than *blocked call*
- Successful handoff access is intimately tied to the radio technology of the channel assignment algorithm
  - The *nonprioritized* scheme
  - The *reserved channel* scheme
  - The *queueing priority* scheme
  - The *subrating* scheme

Handoff Procedure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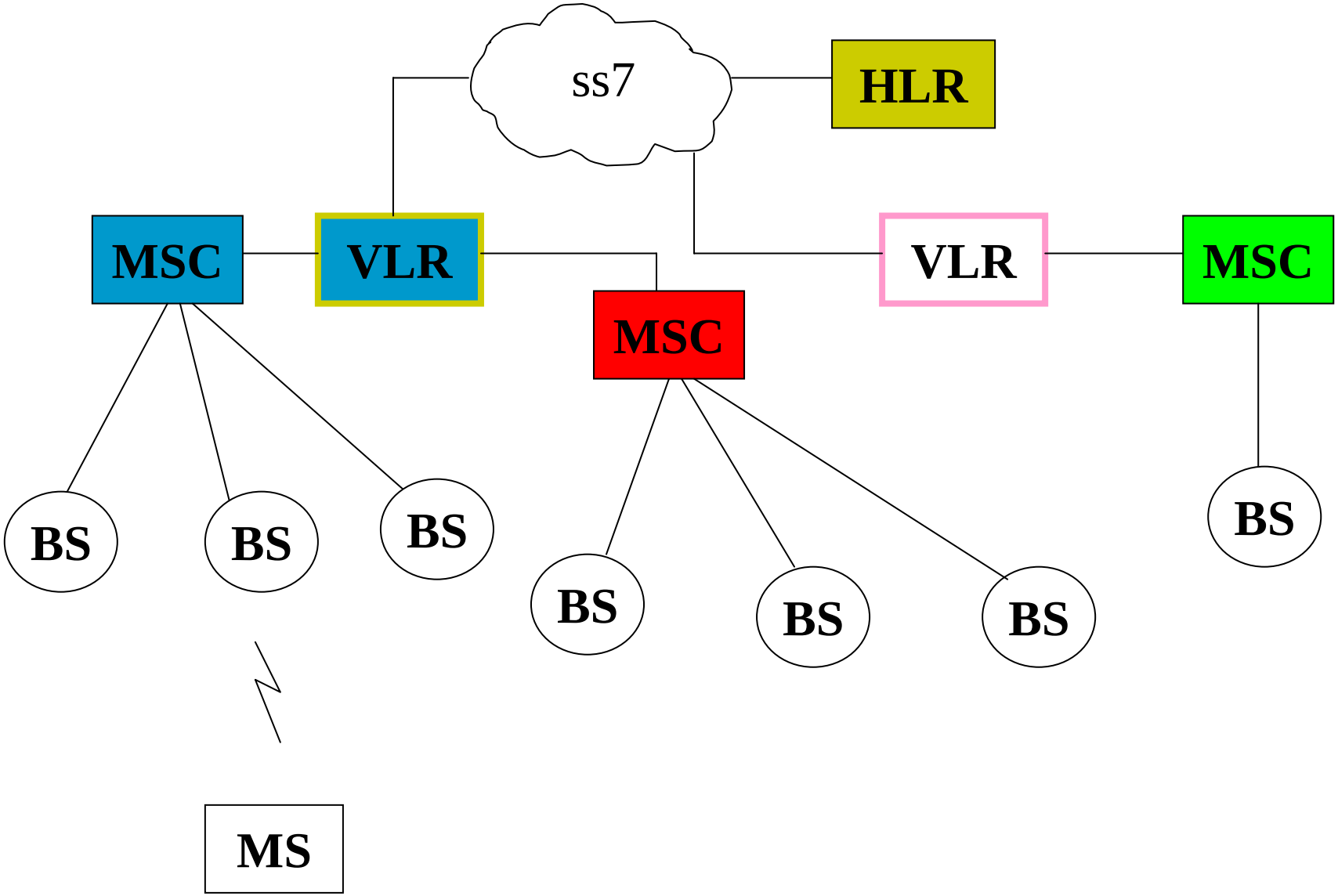
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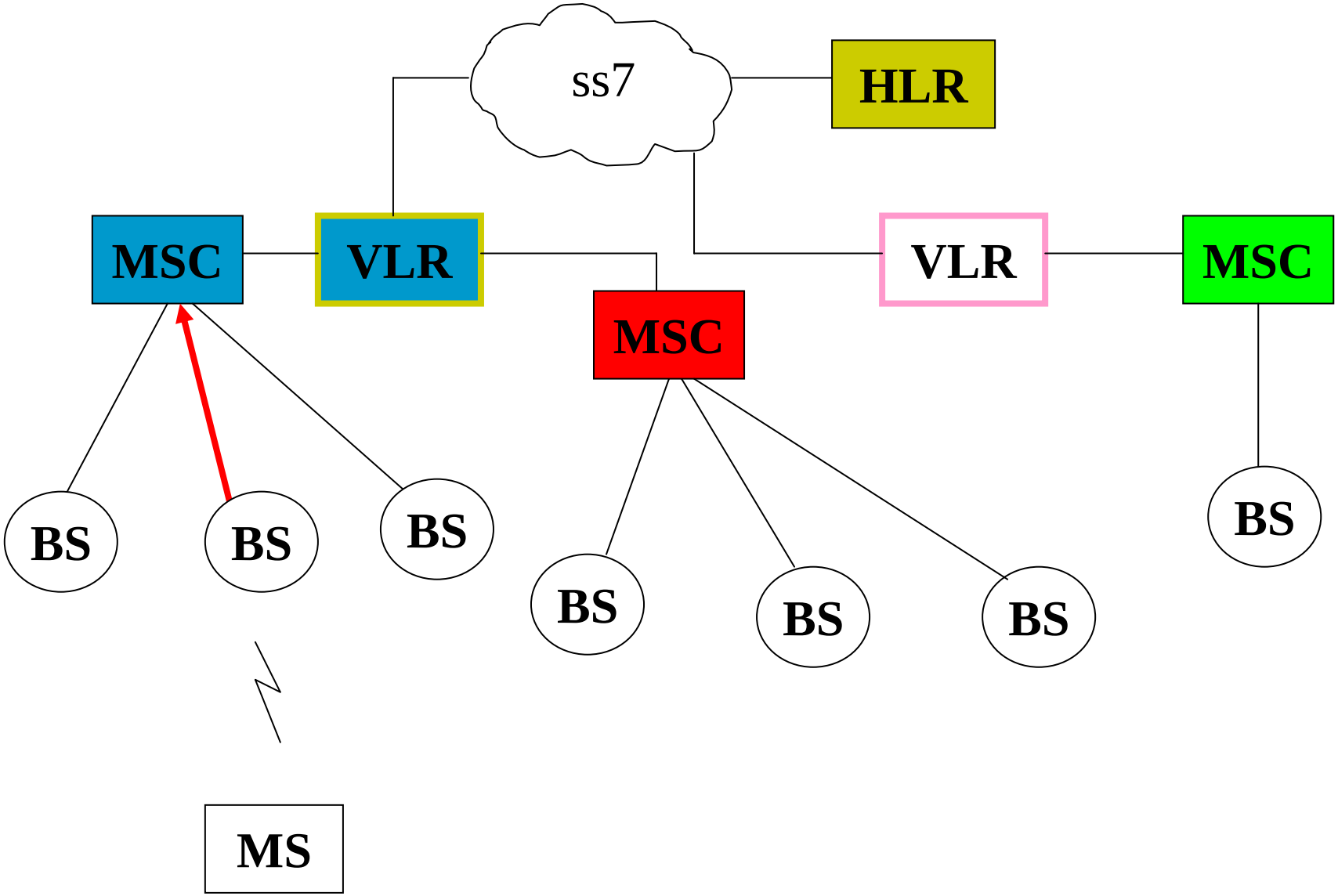
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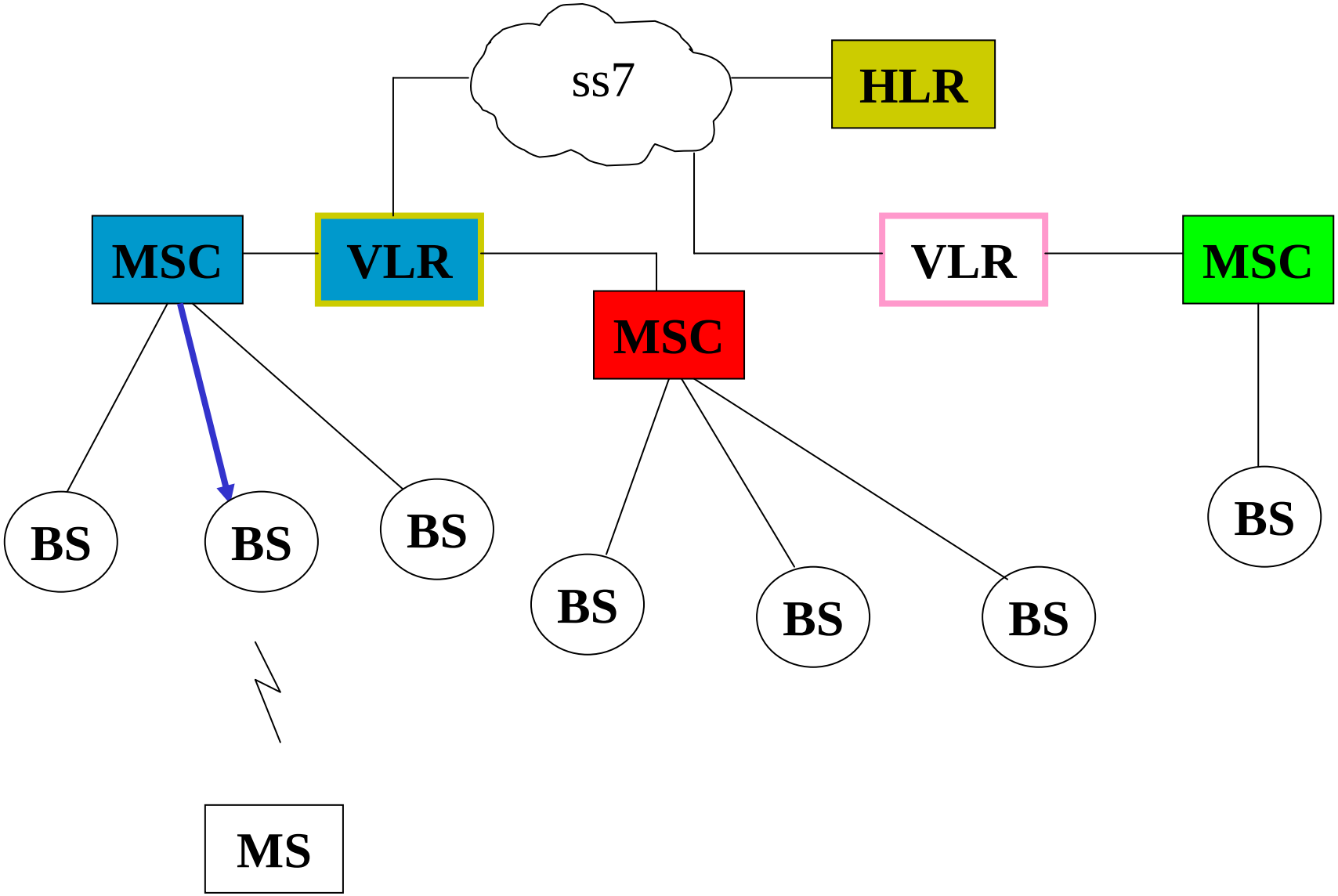
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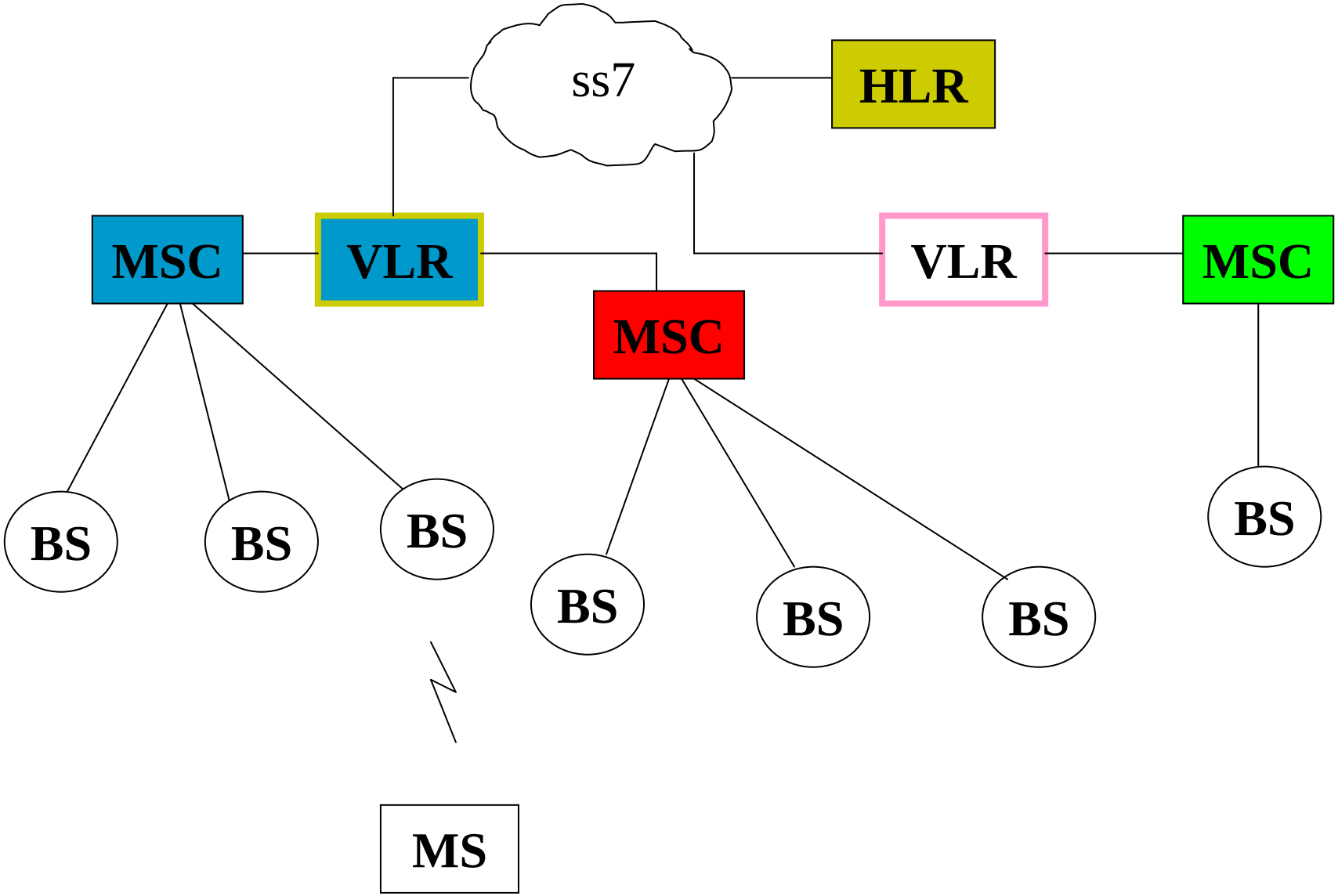
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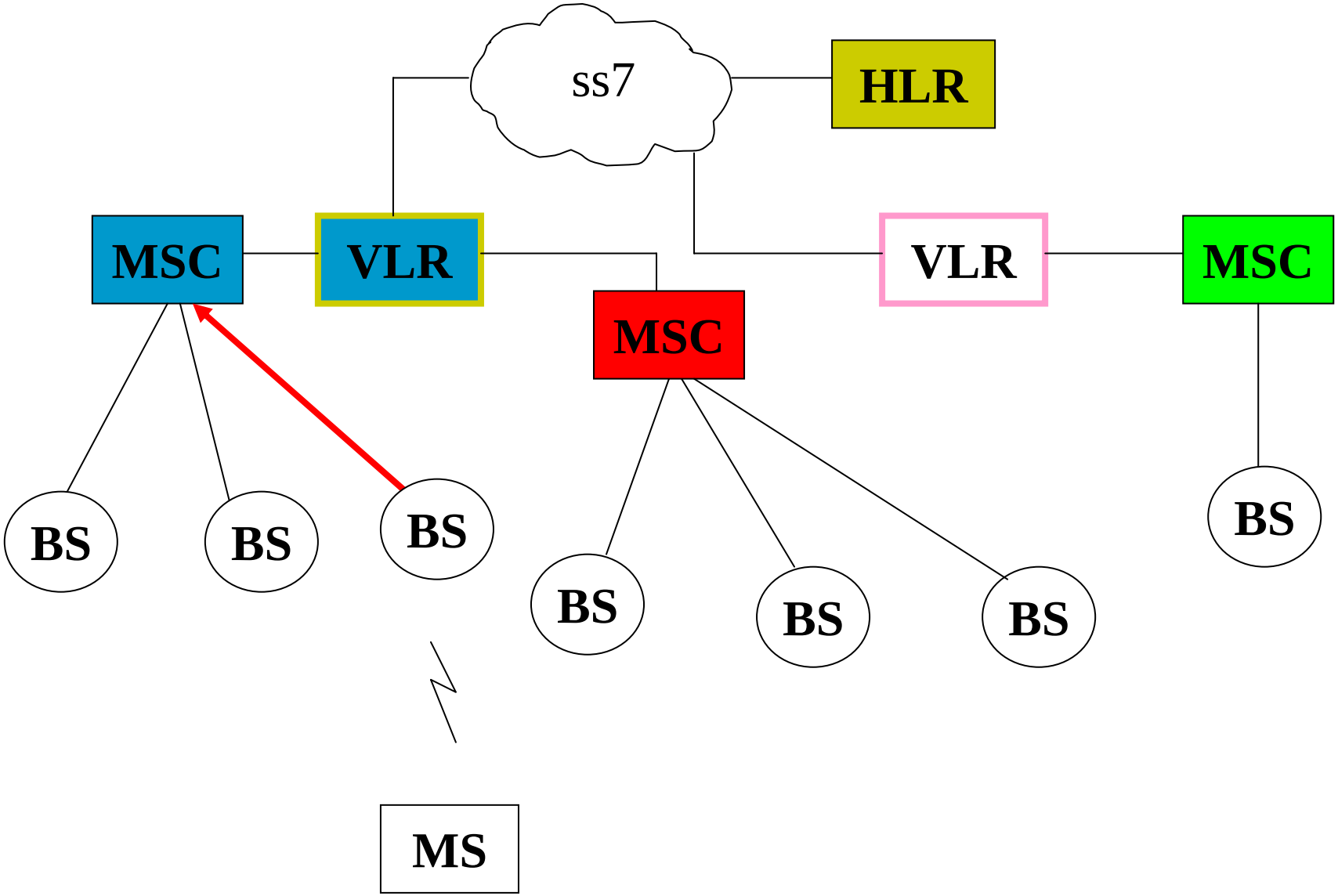
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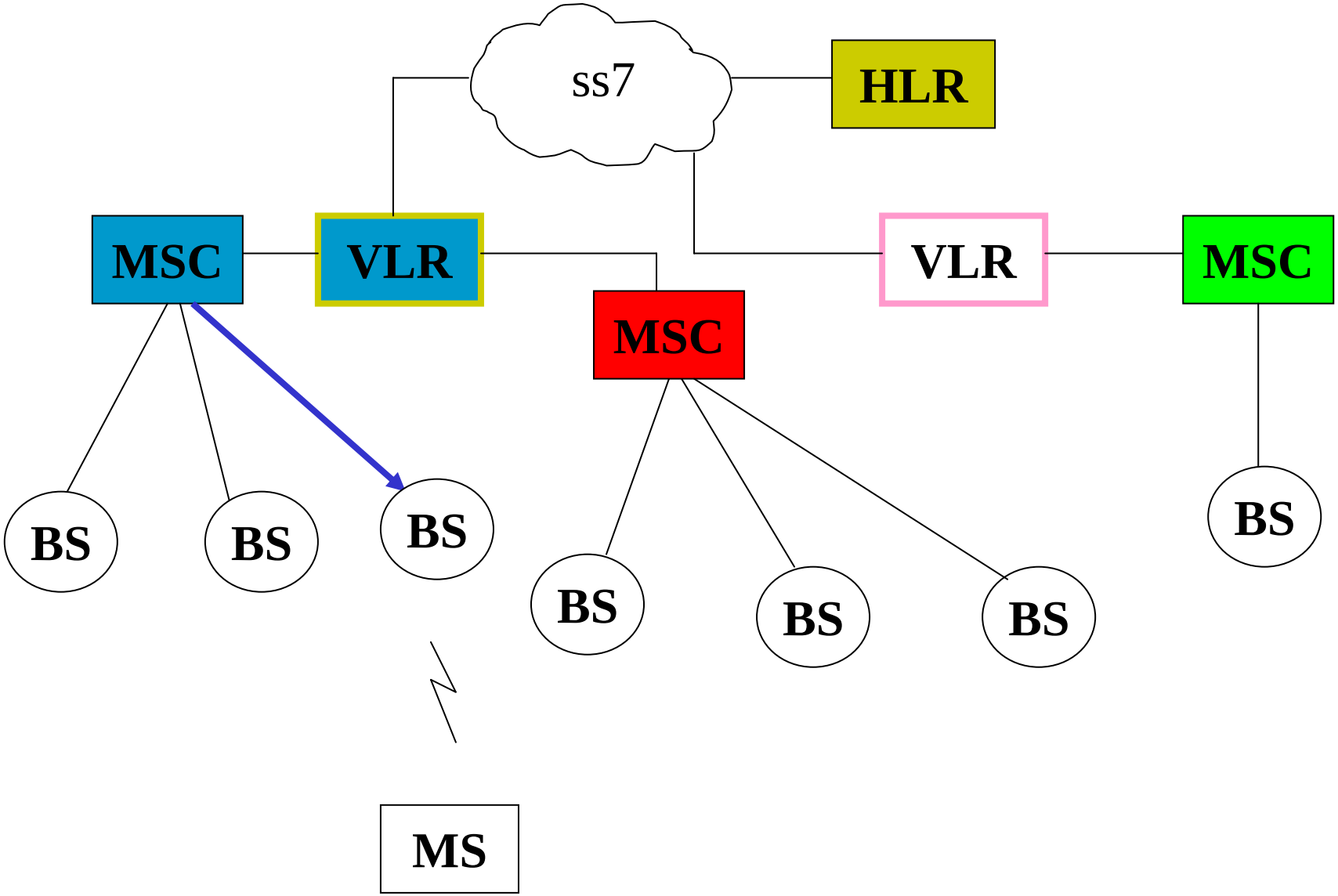
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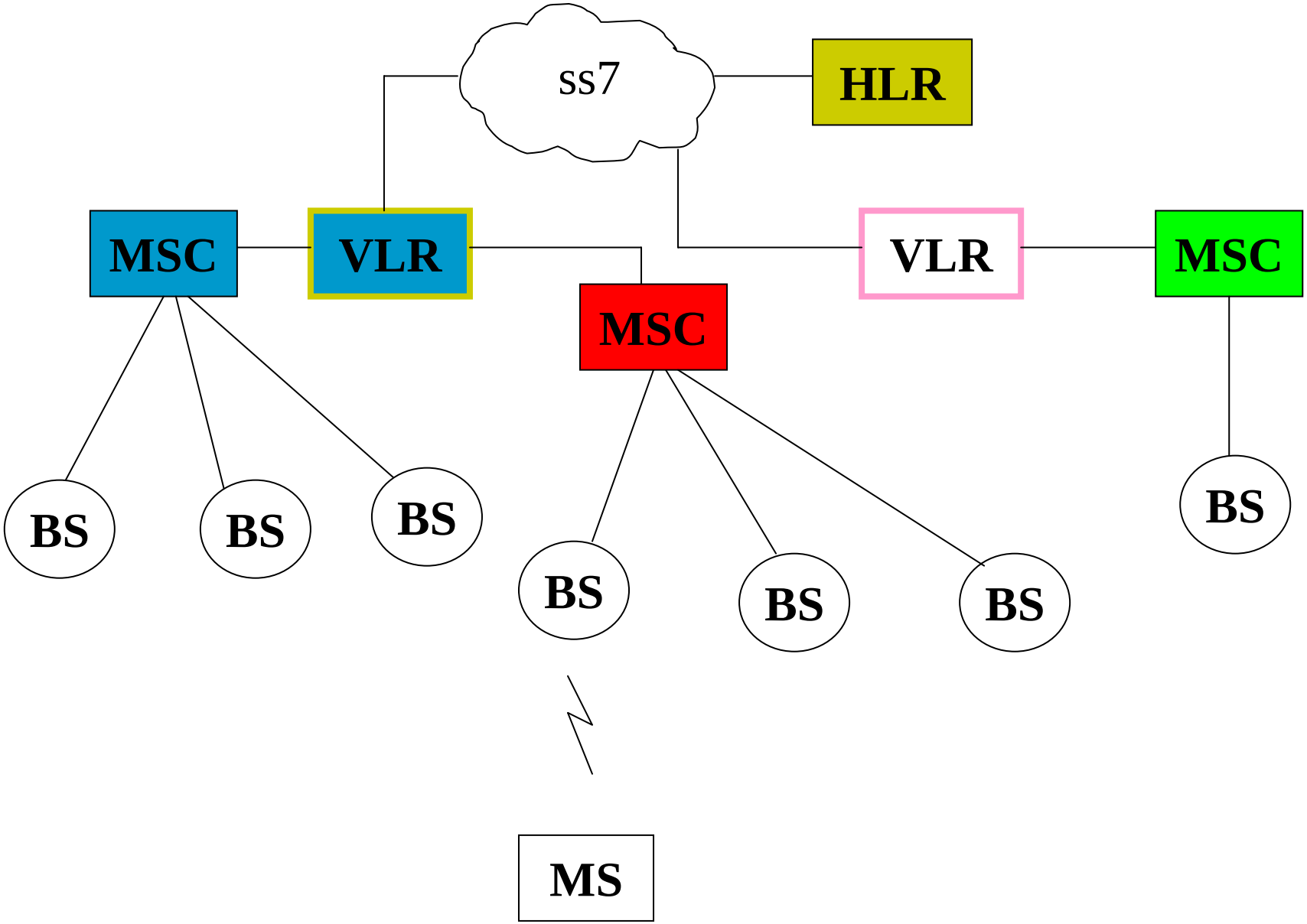
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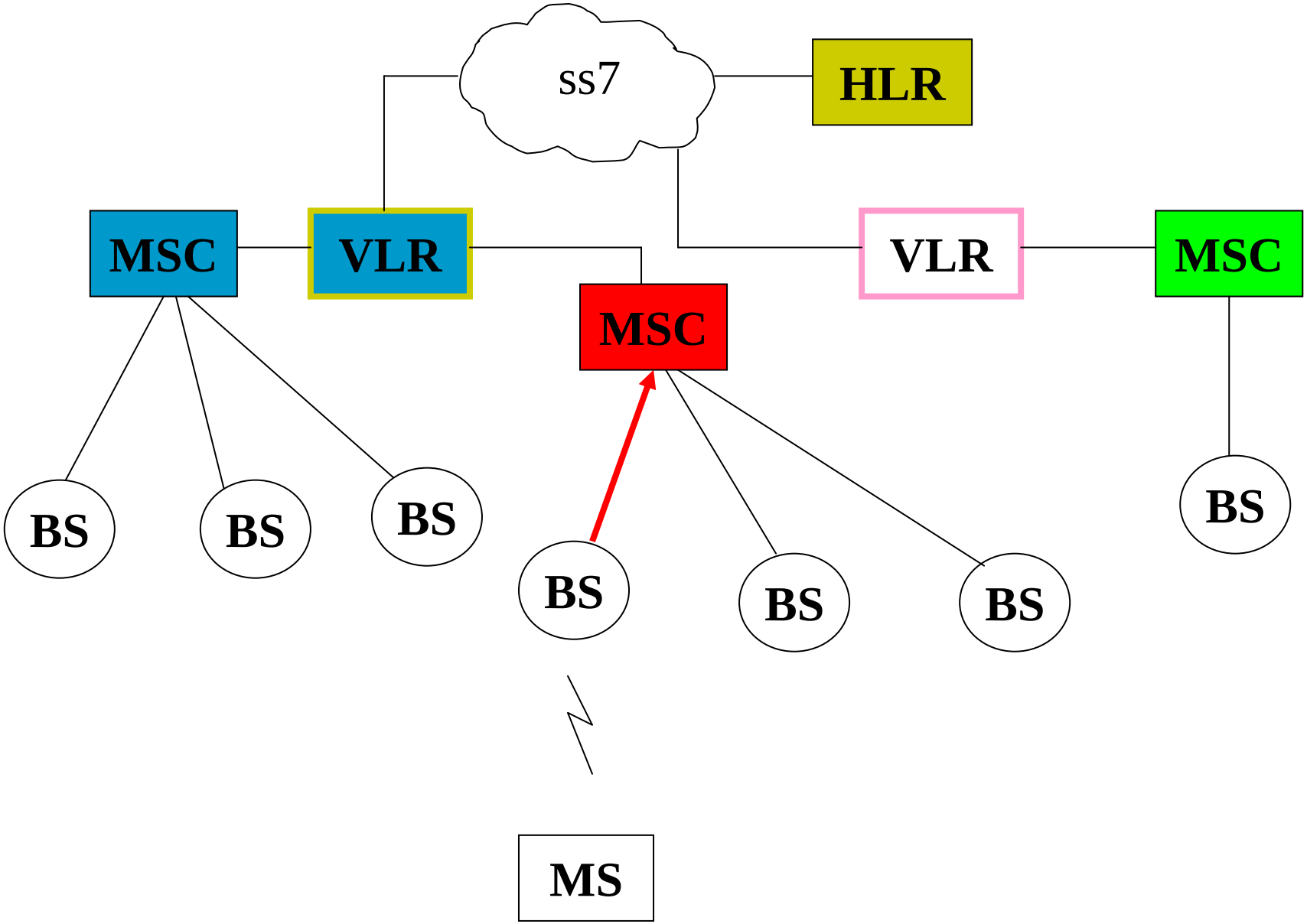
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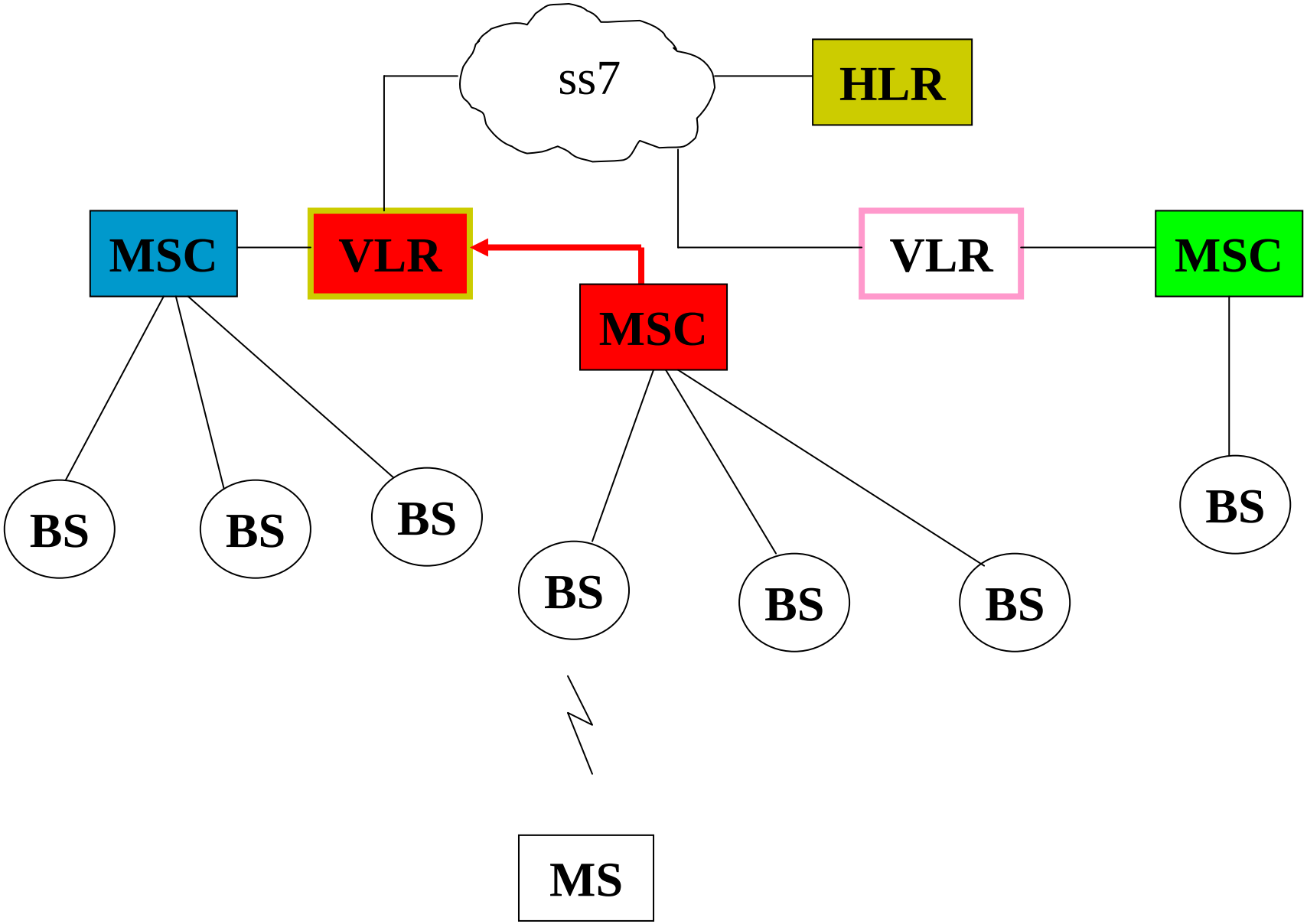
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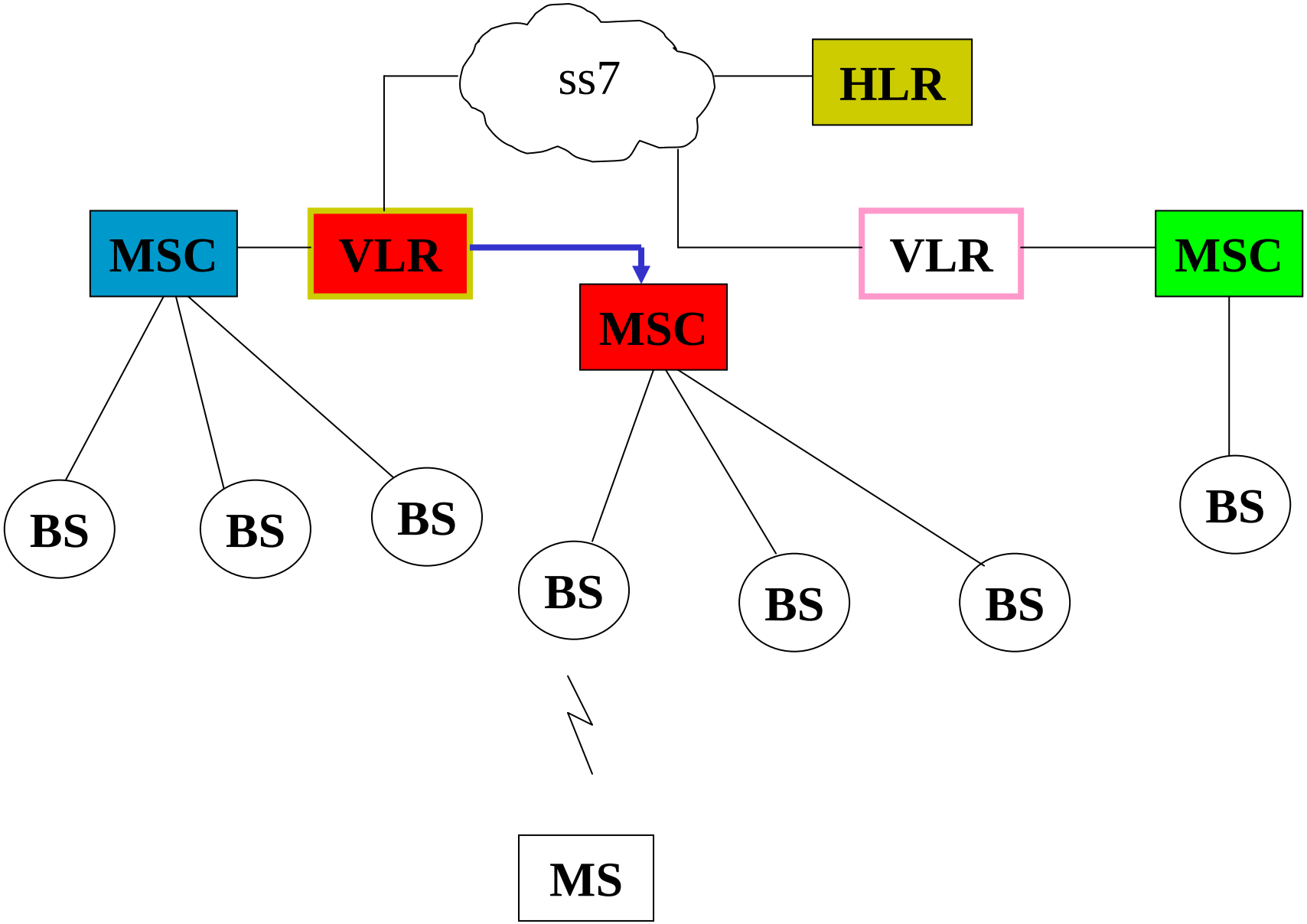
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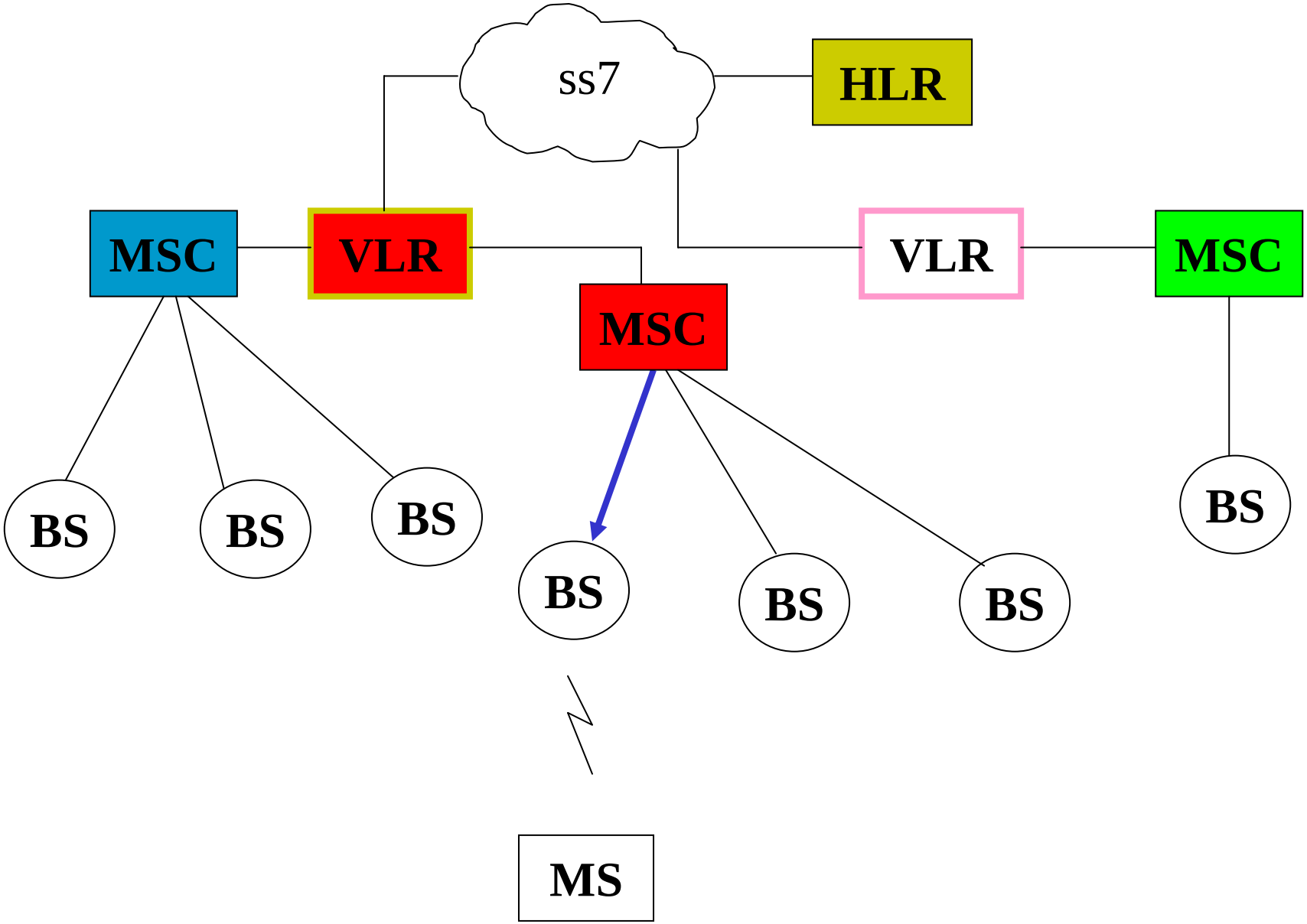
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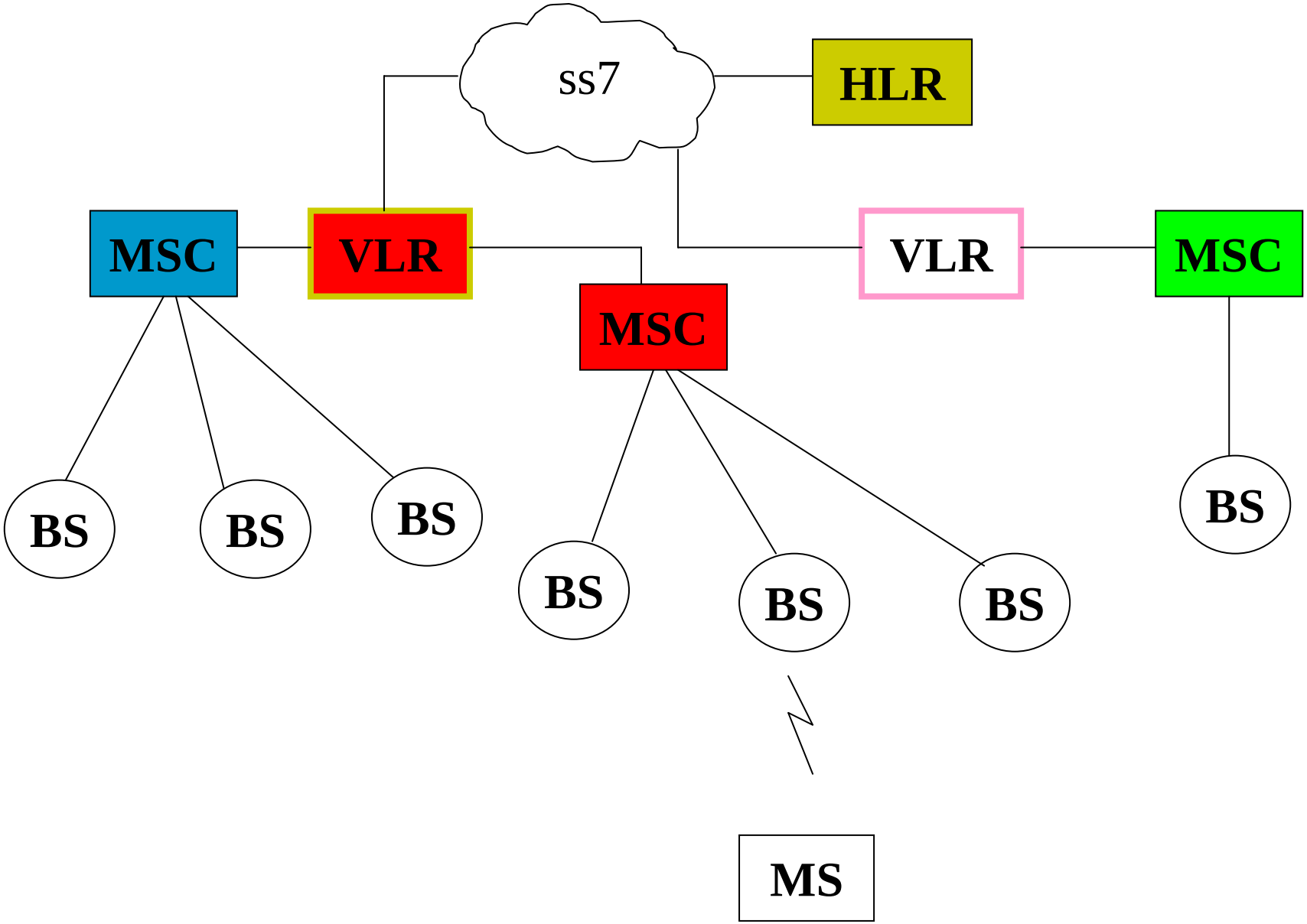
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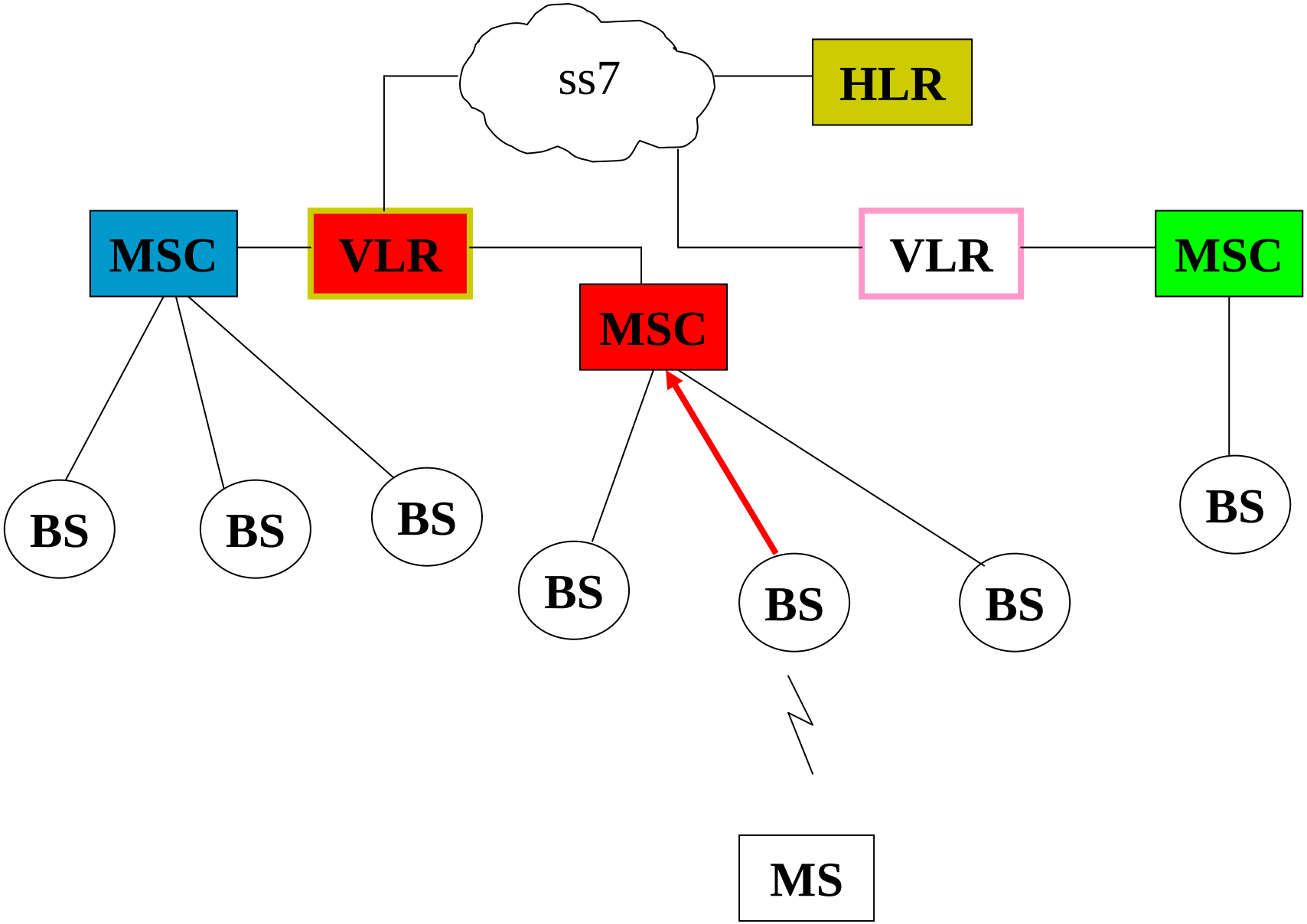
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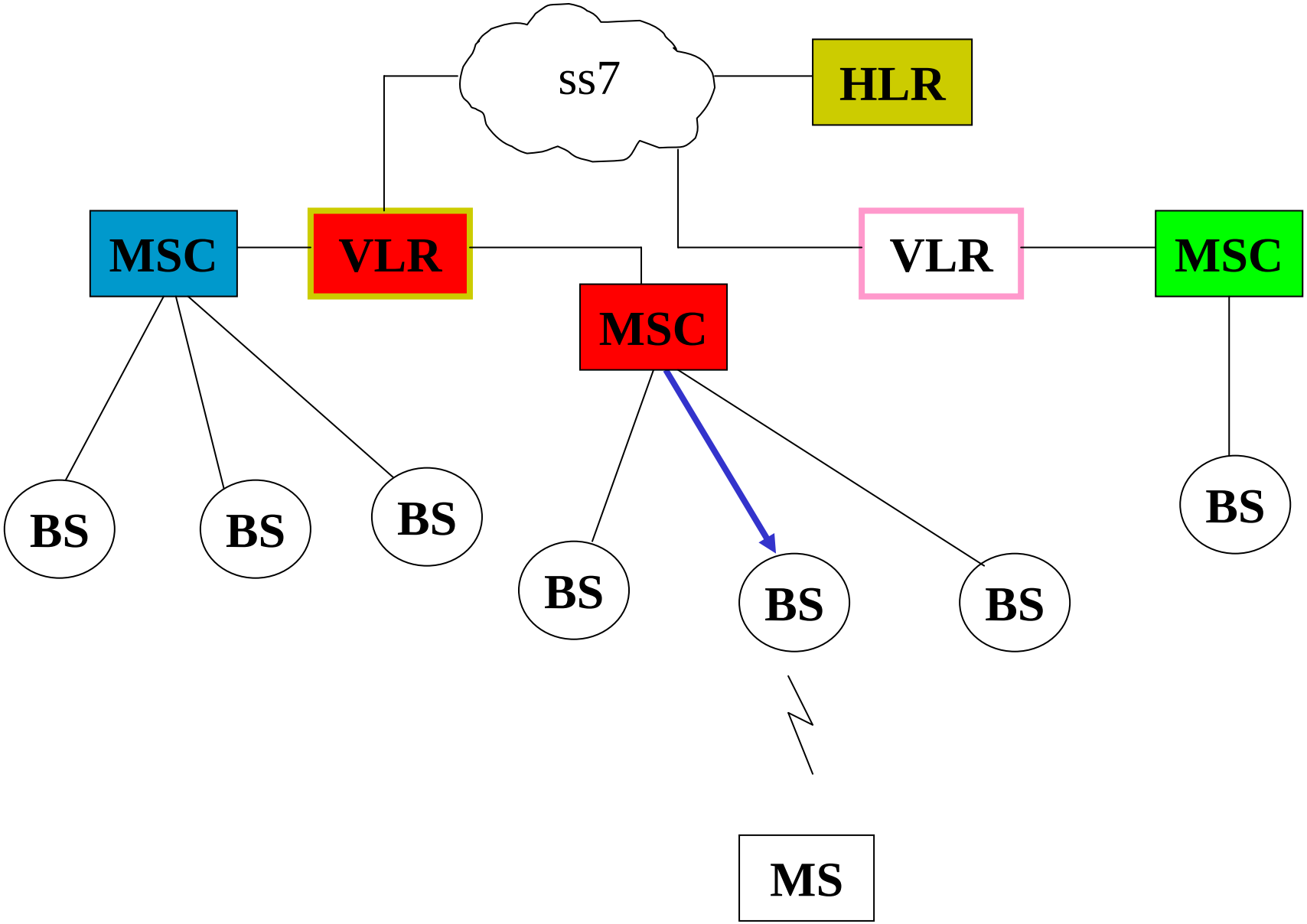
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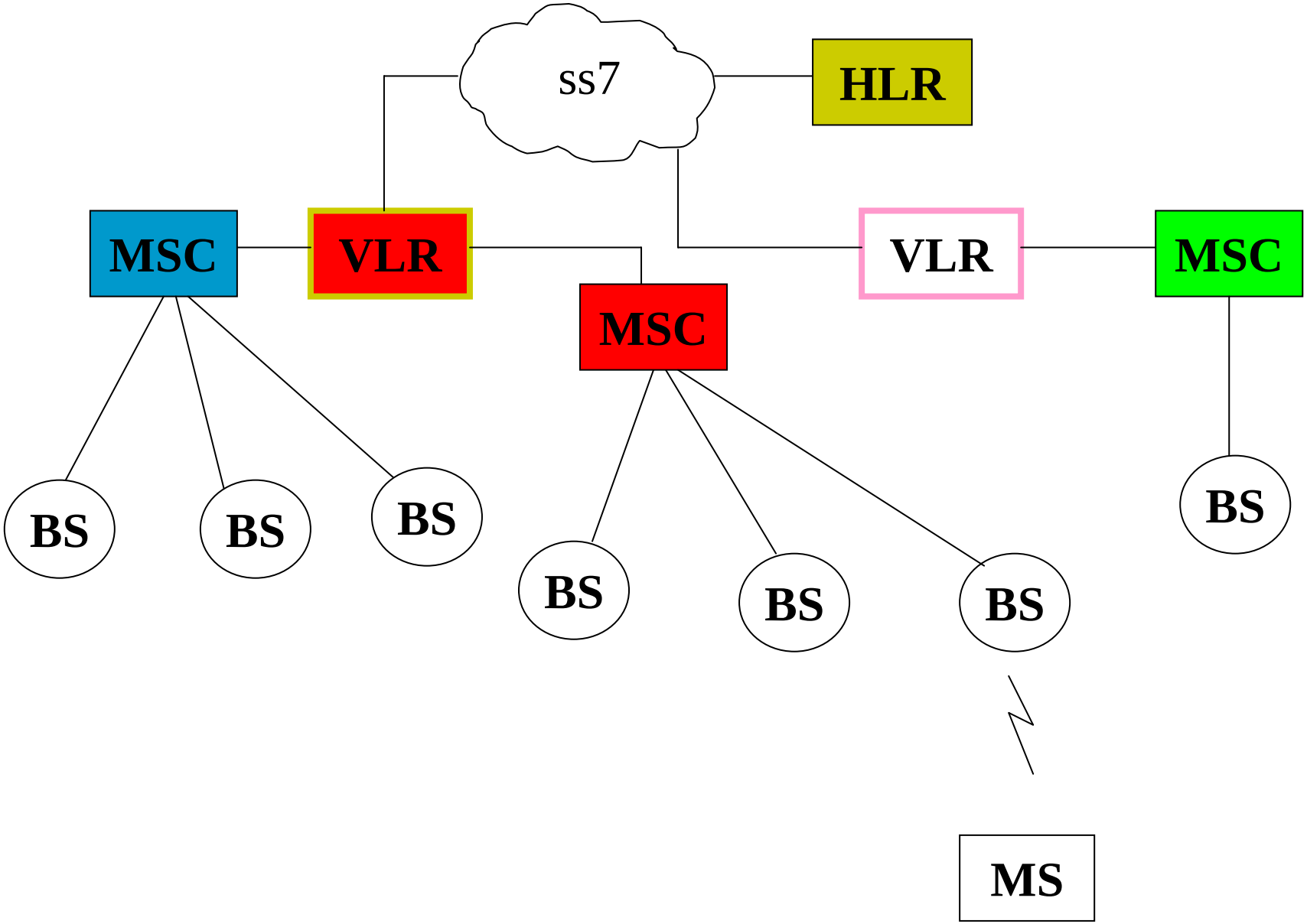
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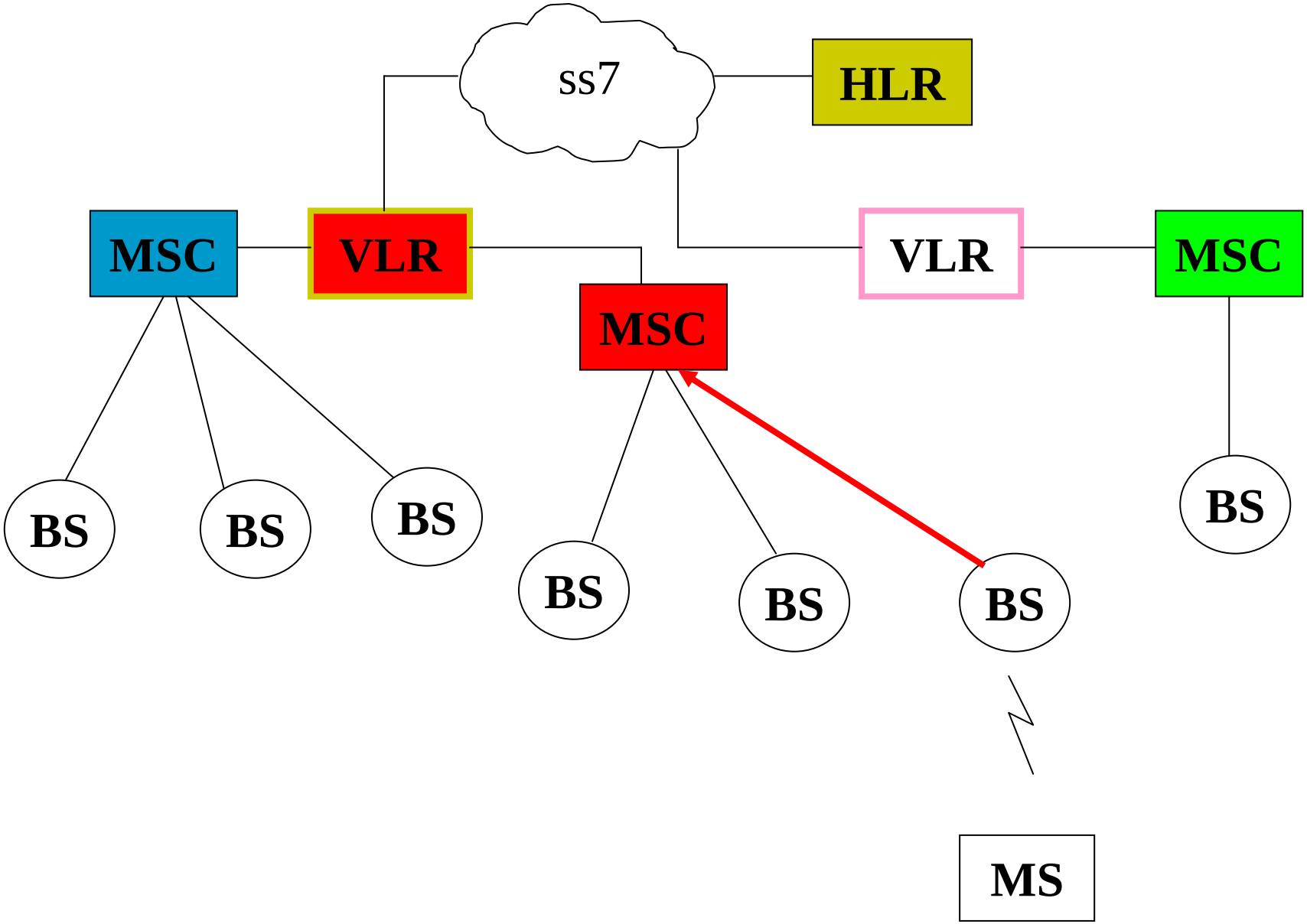
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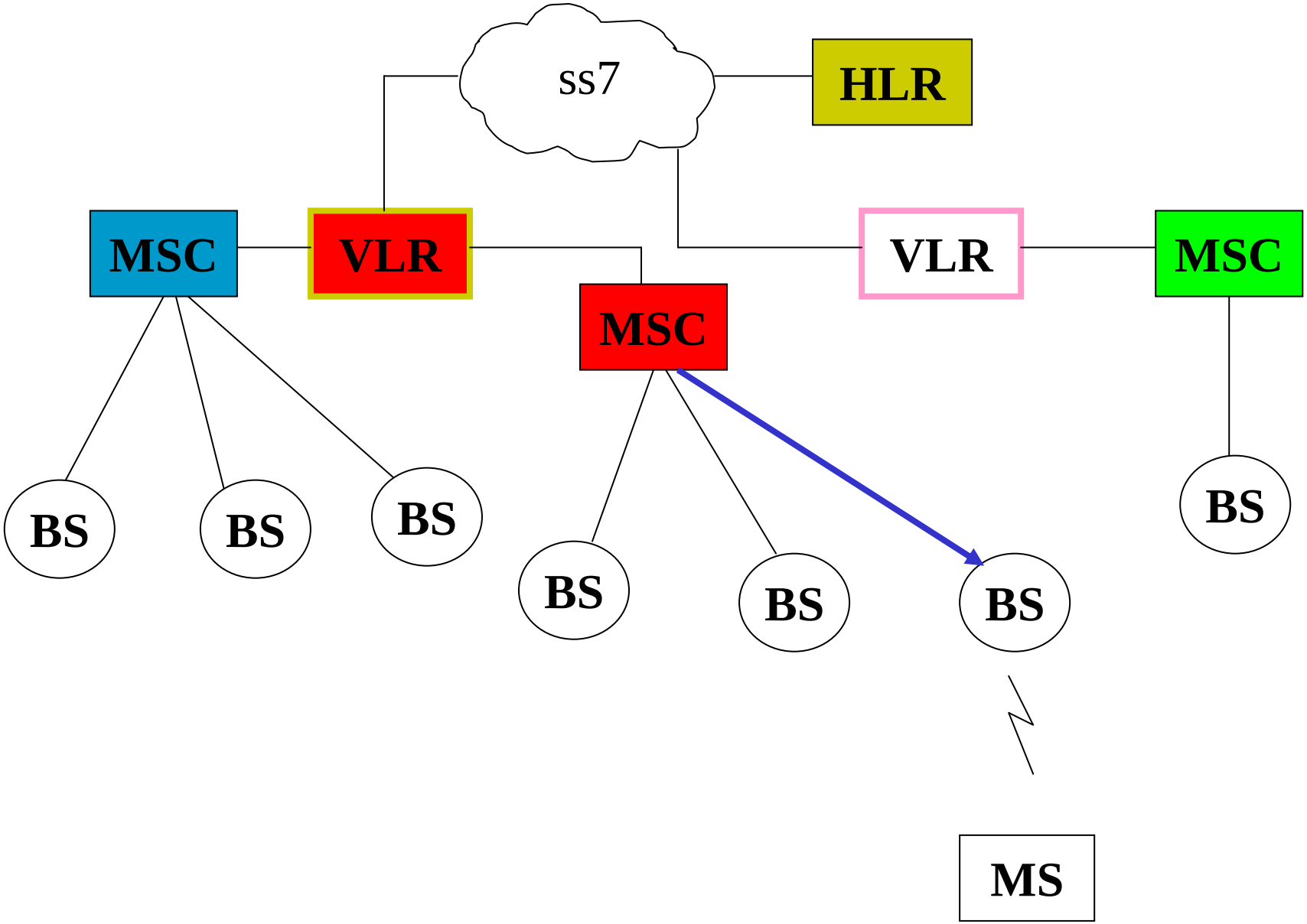
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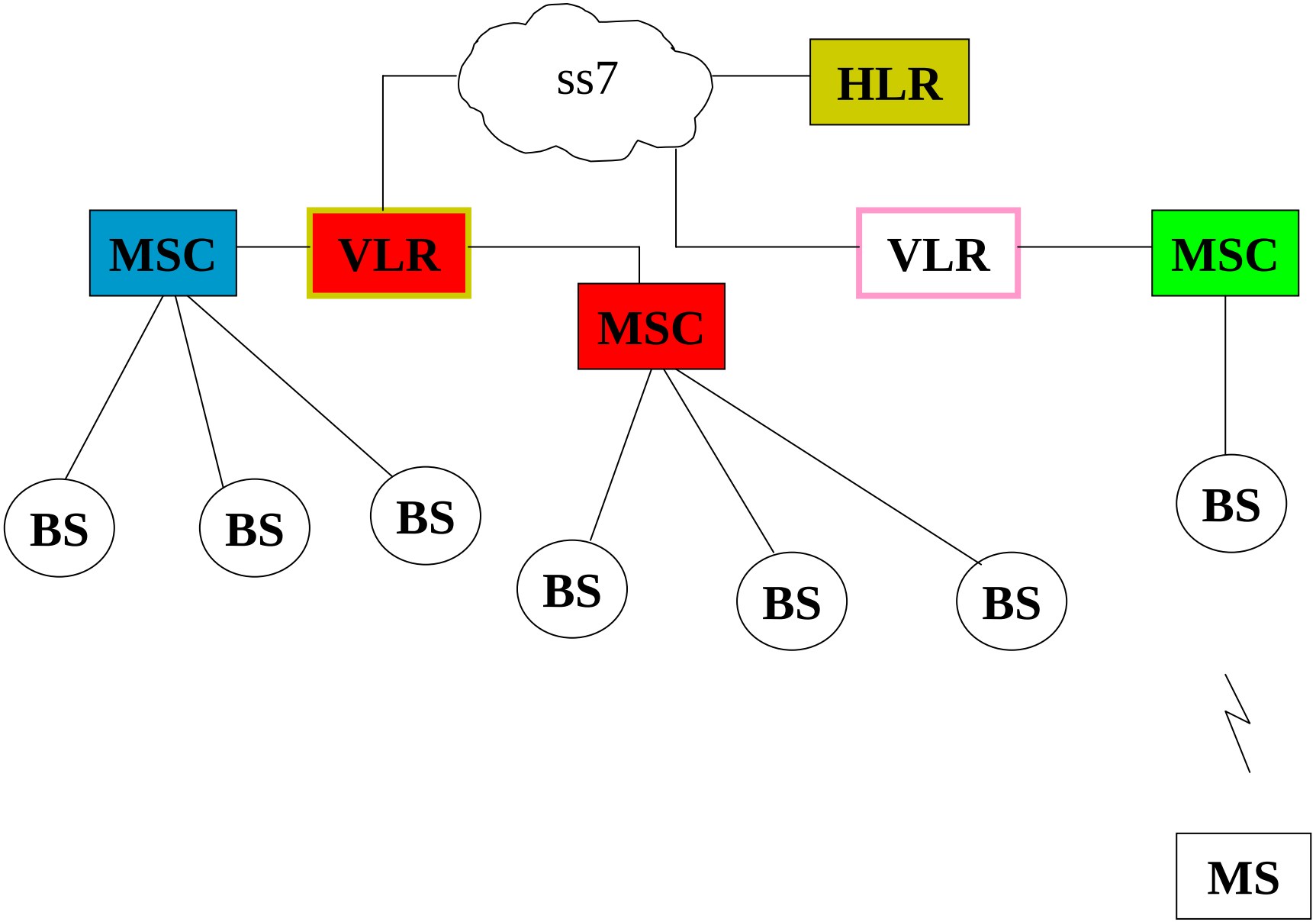
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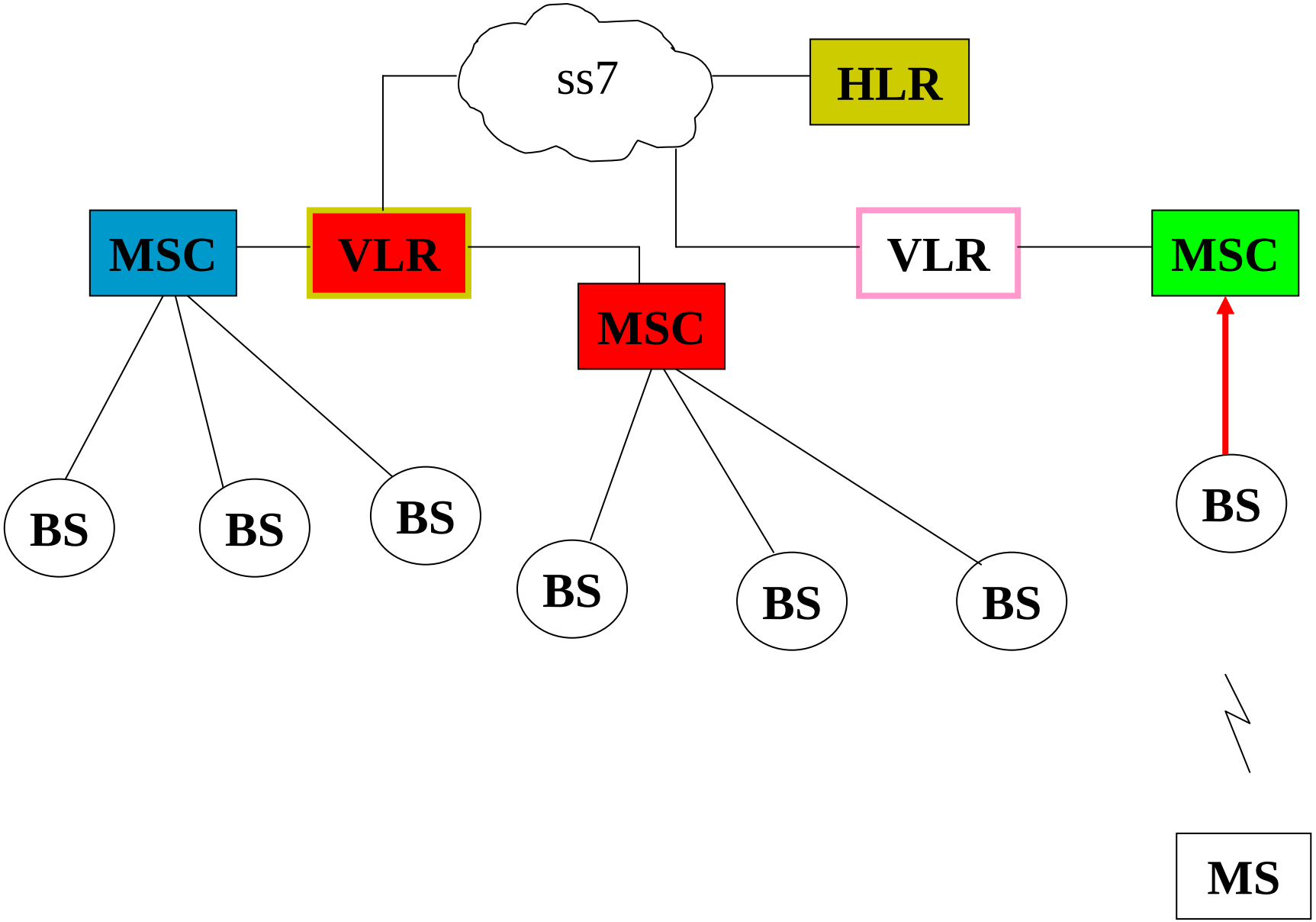
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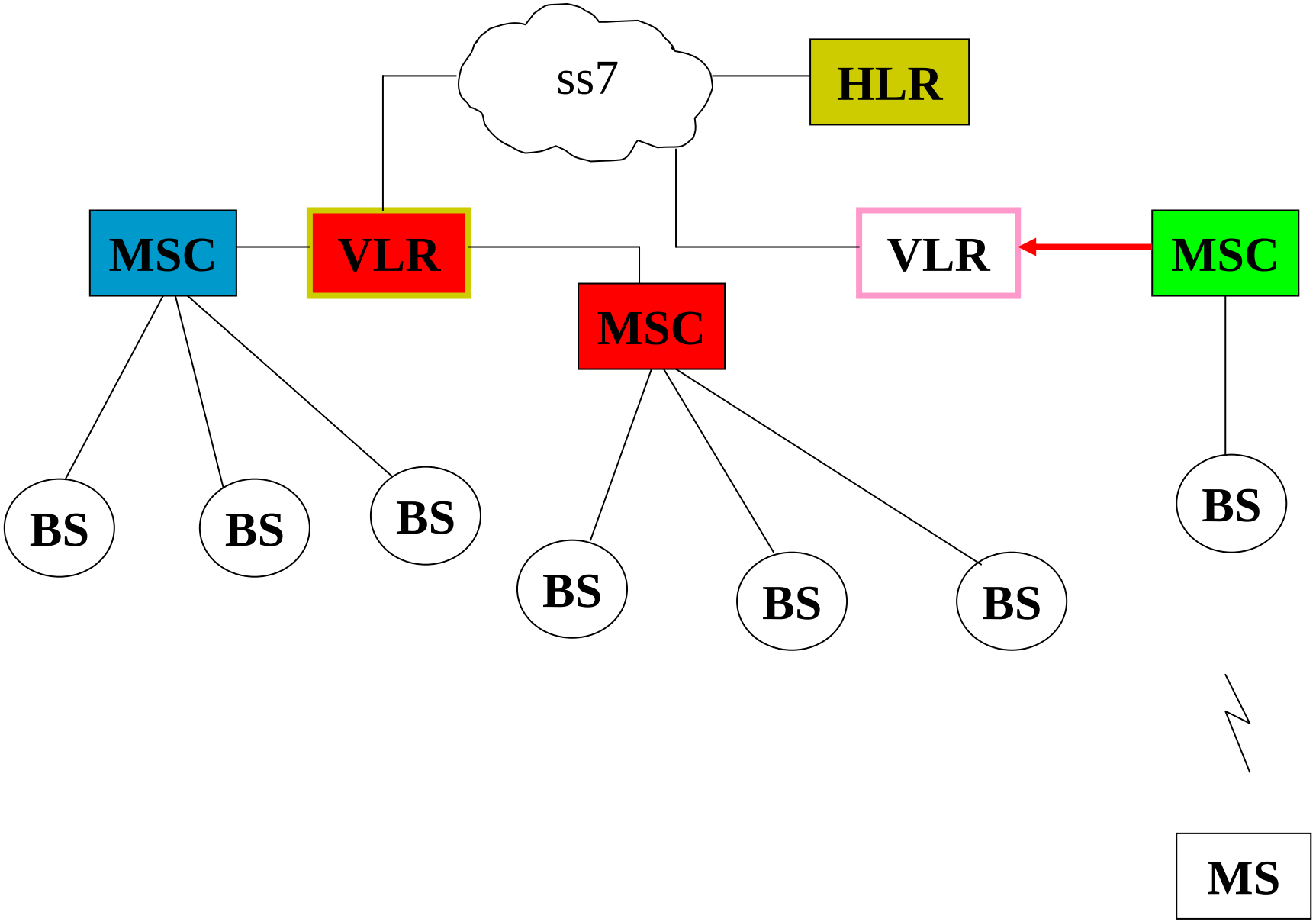
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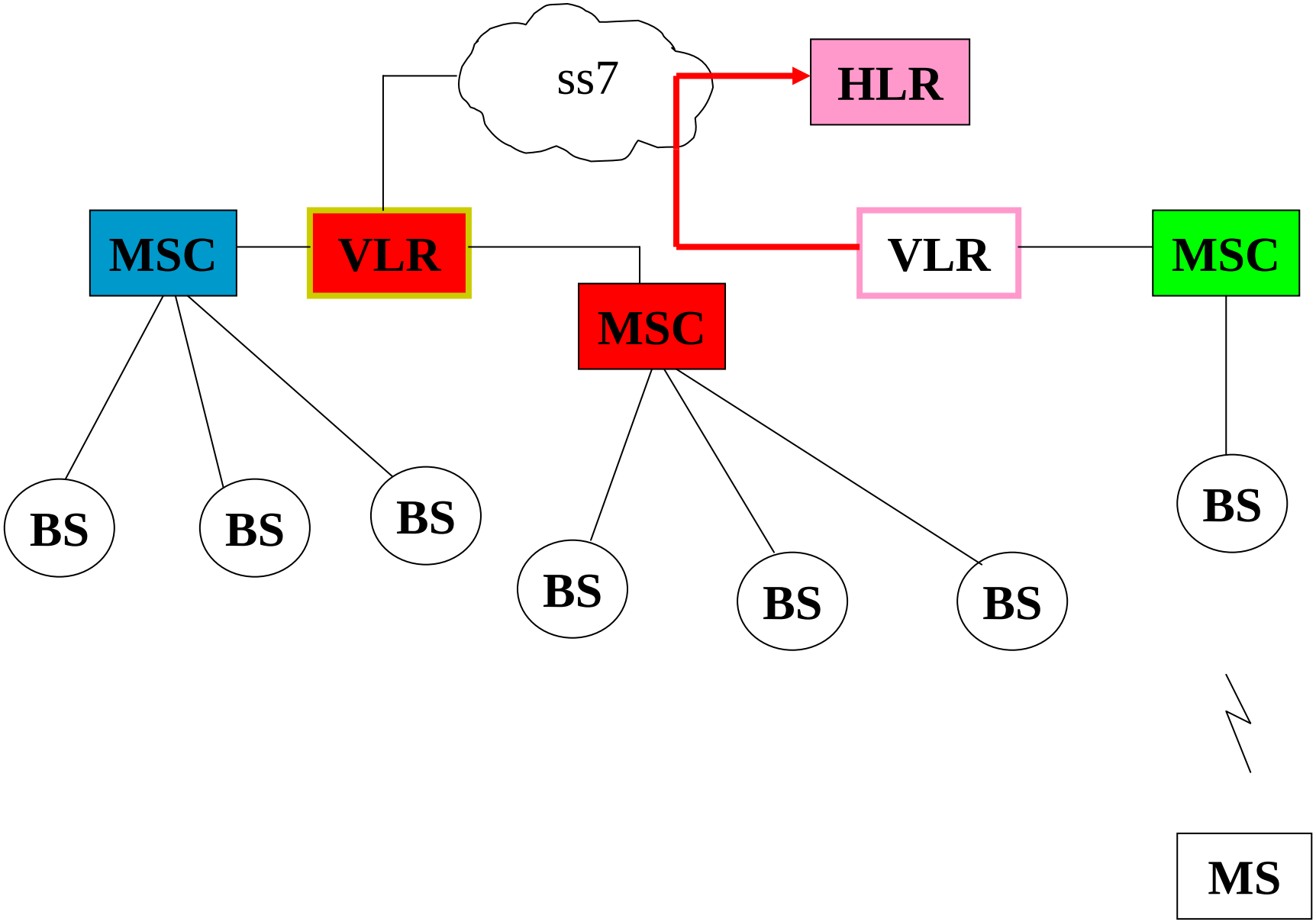
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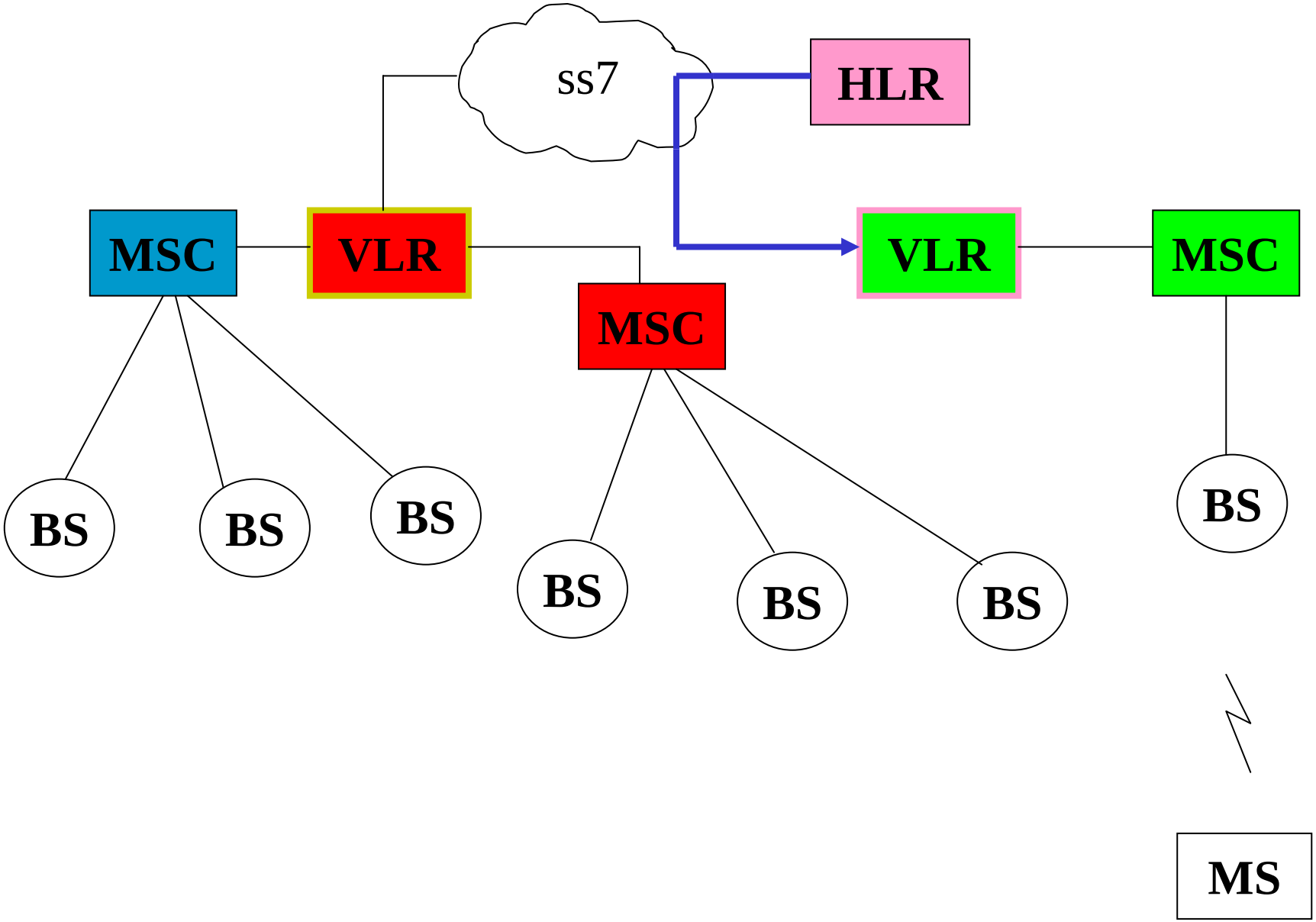
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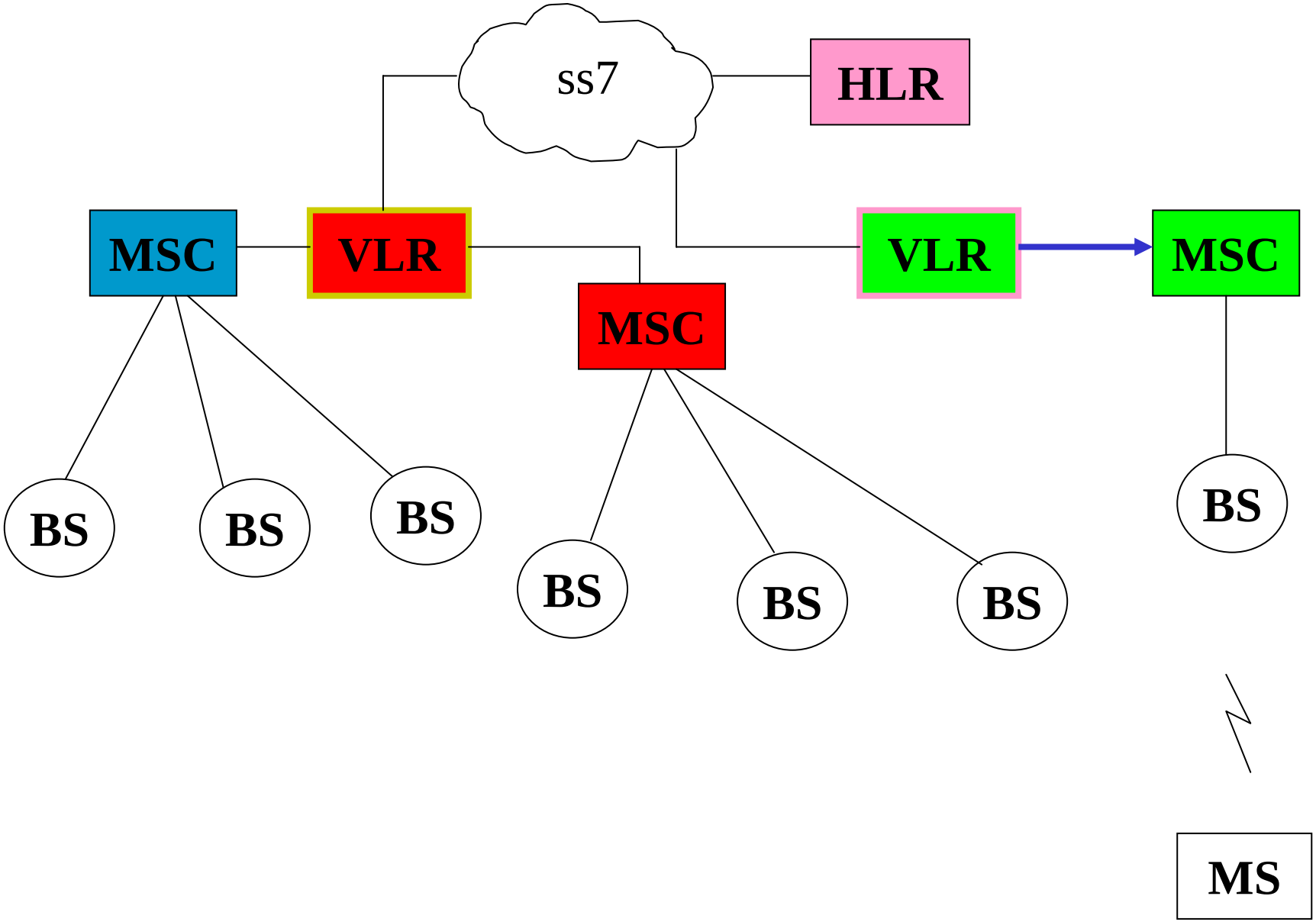
ss7
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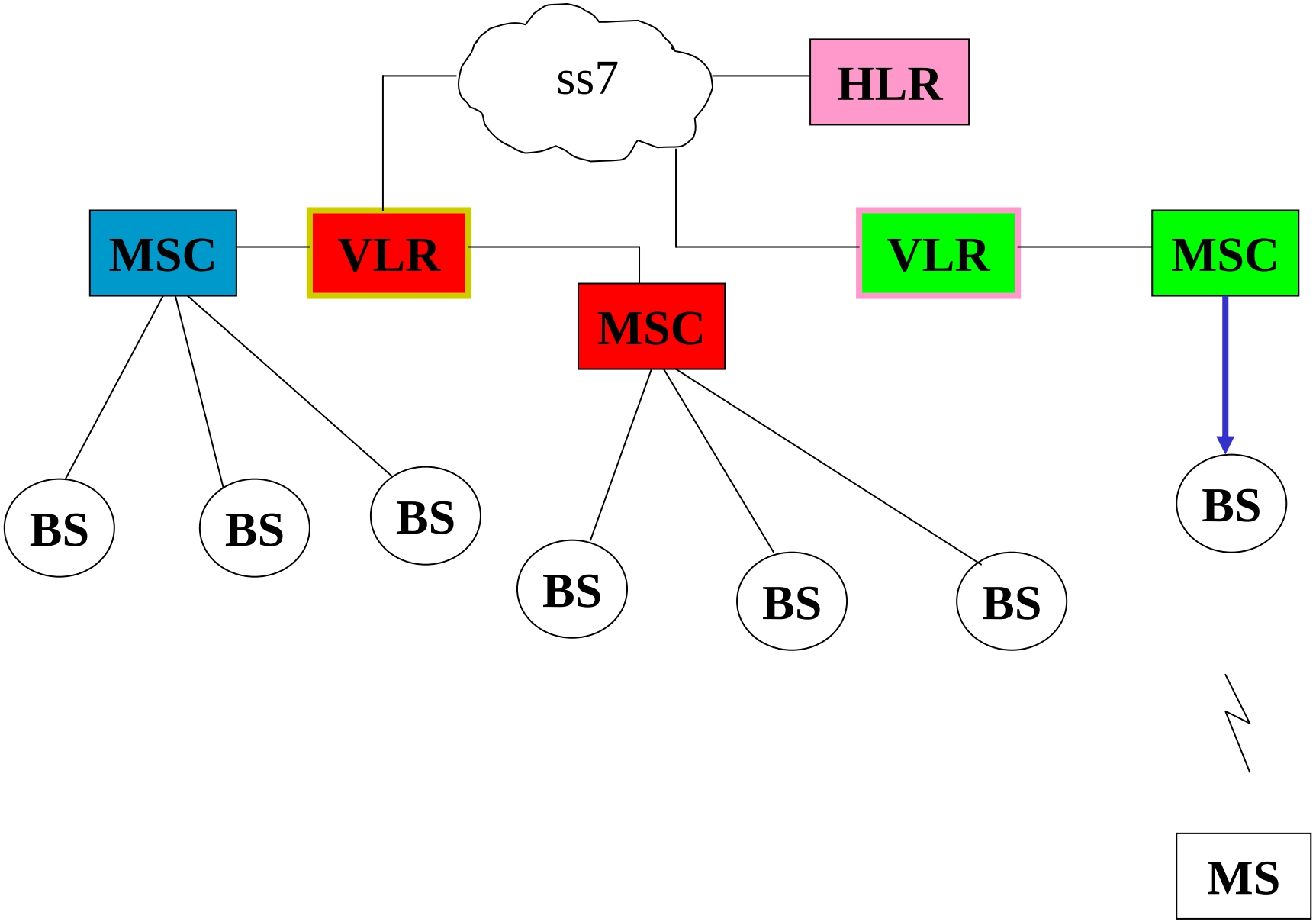
ss7
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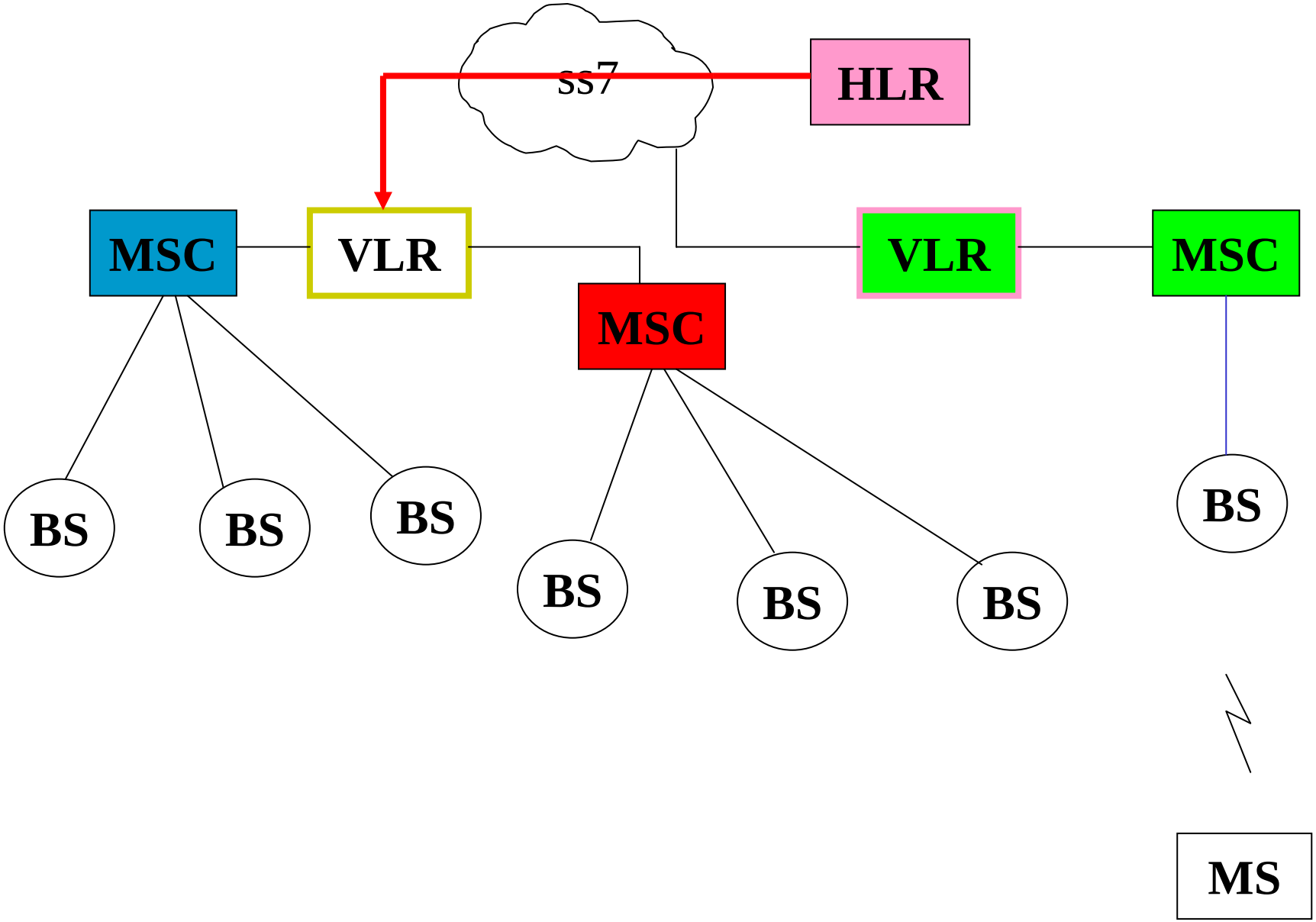
ss7
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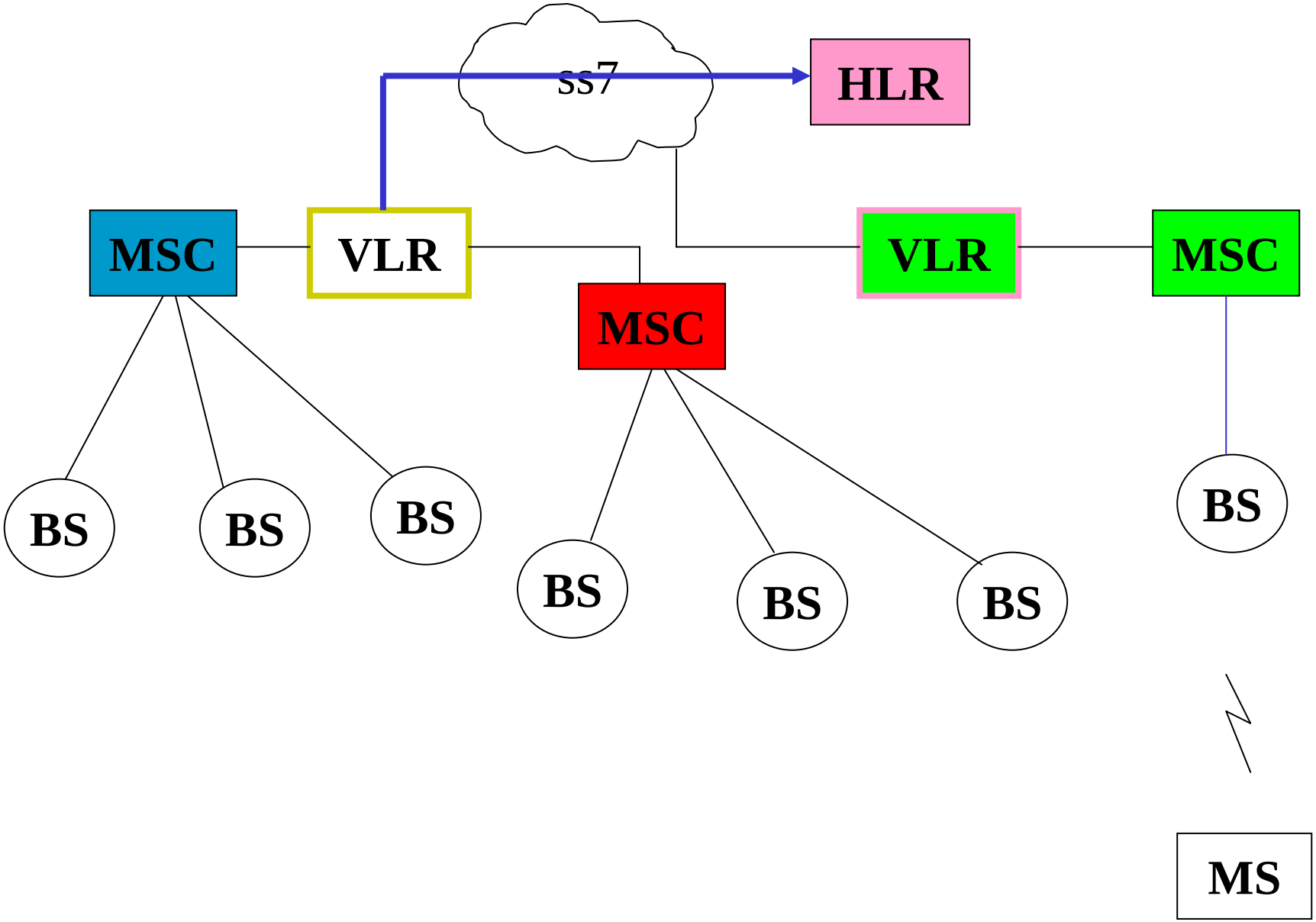
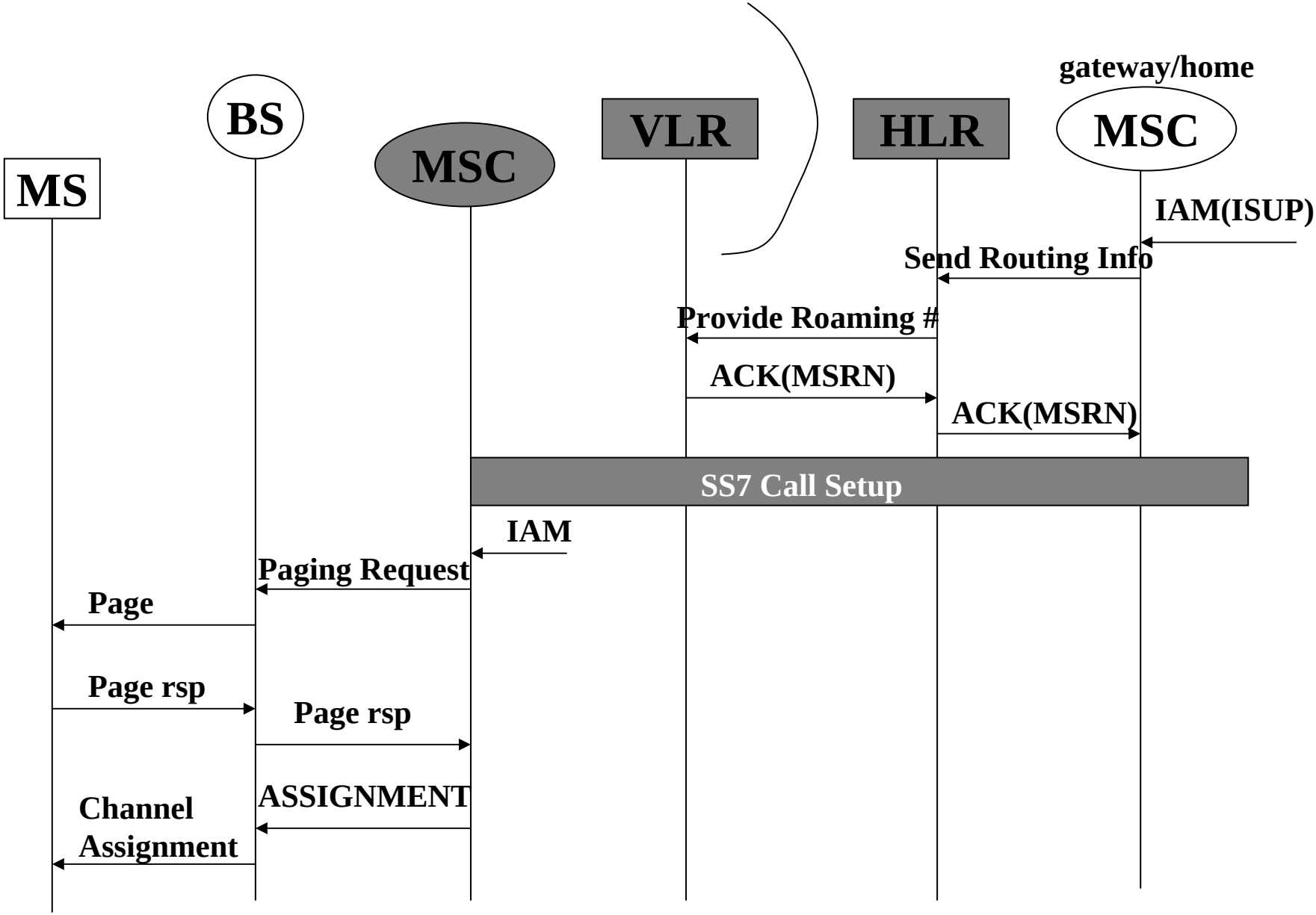

ss7
HLR
MSC
VLR
VLR
MSC
MSC
BS
BS
BS
BS
BS
BS
BS
MS

Call Delivery

Call Delivery

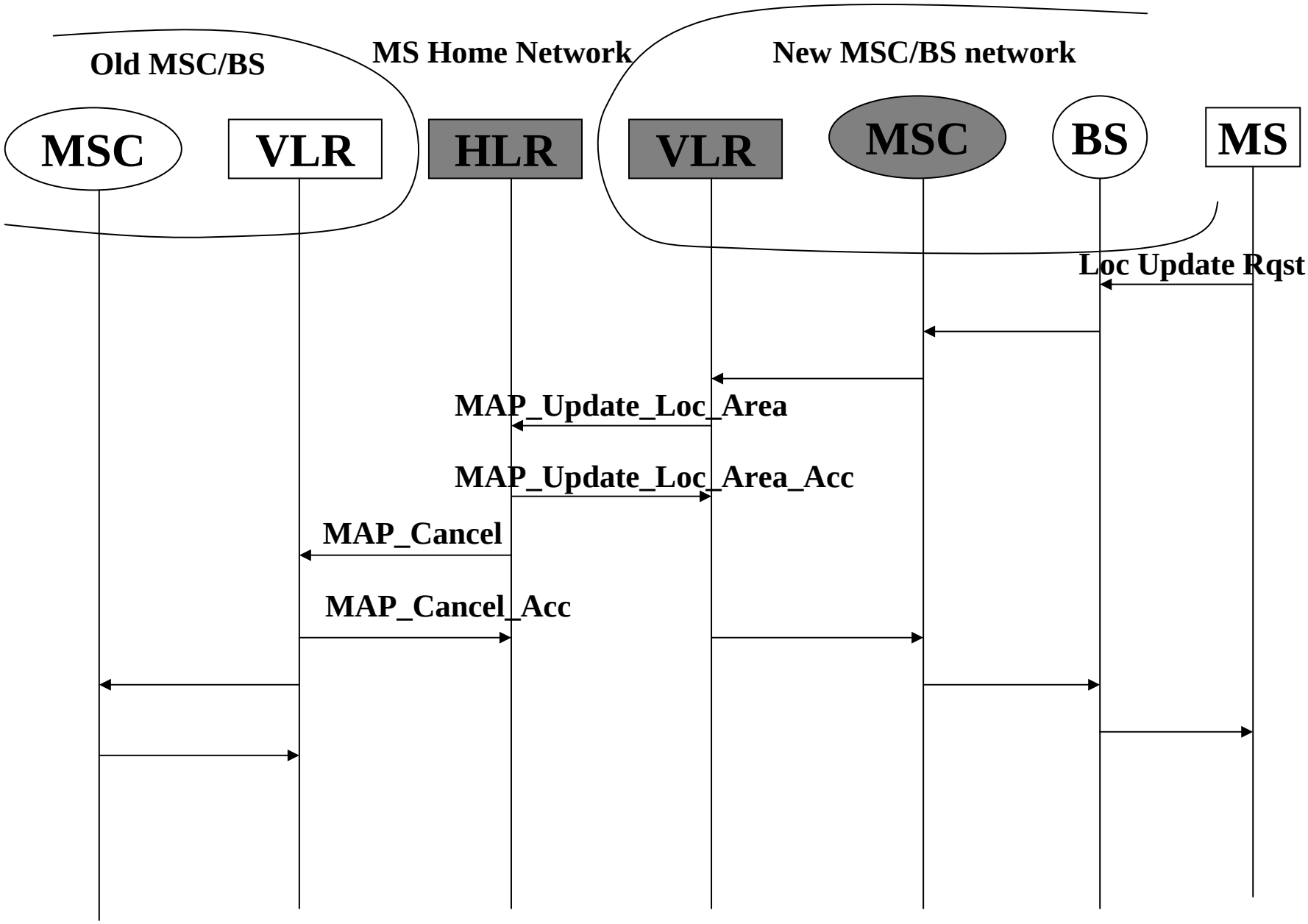
- The other user call the mobile
  - Find out where is the mobile
  - Establish the call


MS
BS
MSC
VLR
HLR
gateway/home
MSC
IAM(ISUP)
Send Routing Info
Provide Roaming #
ACK(MSRN)
ACK(MSRN)
SS7 Call Setup
IAM
Paging Request
Page
Page rsp
Page rsp
ASSIGNMENT
Channel
Assignment

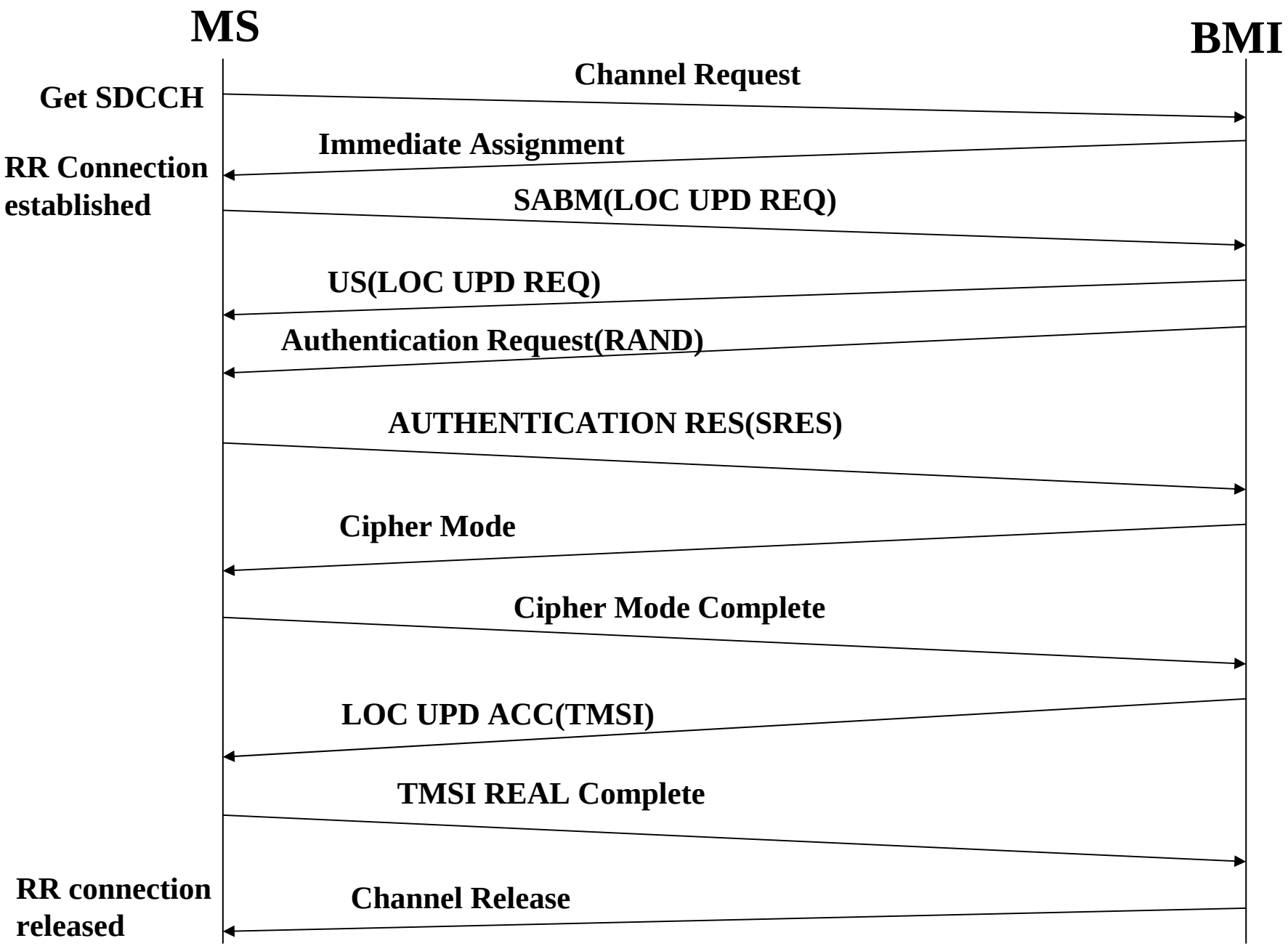
Registration (Network)

Registration

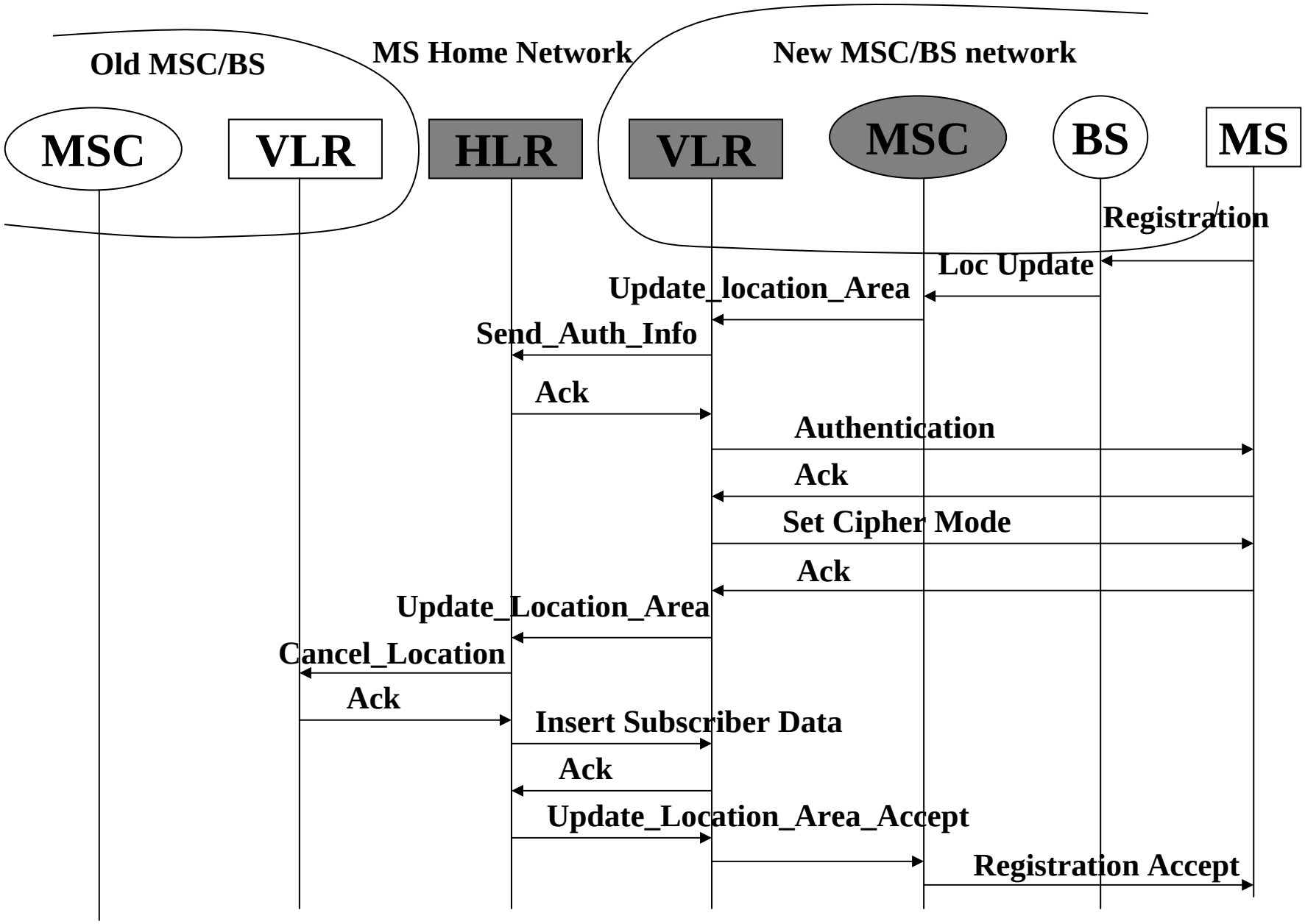
- Mobile register from the new location
  - Mobile moves to a new place
  - Register the new location
    - Update new foreign network
    - Update home network
    - Update (remove old info) old foreign network


Old MSC/BS
MS Home Network
New MSC/BS network
MSC
VLR
HLR
VLR
MSC
BS
MS
Loc Update Rqst
MAP_Update_Loc_Area
MAP_Update_Loc_Area_Acc
MAP_Cancel
MAP_Cancel_Acc

GSM Registration (Air Interface)


MS
BMI
Get SDCCH
Channel Request
Immediate Assignment
RR Connection established
SABM(LOC UPD REQ)
US(LOC UPD REQ)
Authentication Request(RAND)
AUTHENTICATION RES(SRES)
Cipher Mode
Cipher Mode Complete
LOC UPD ACC(TMSI)
TMSI REAL Complete
RR connection released
Channel Release

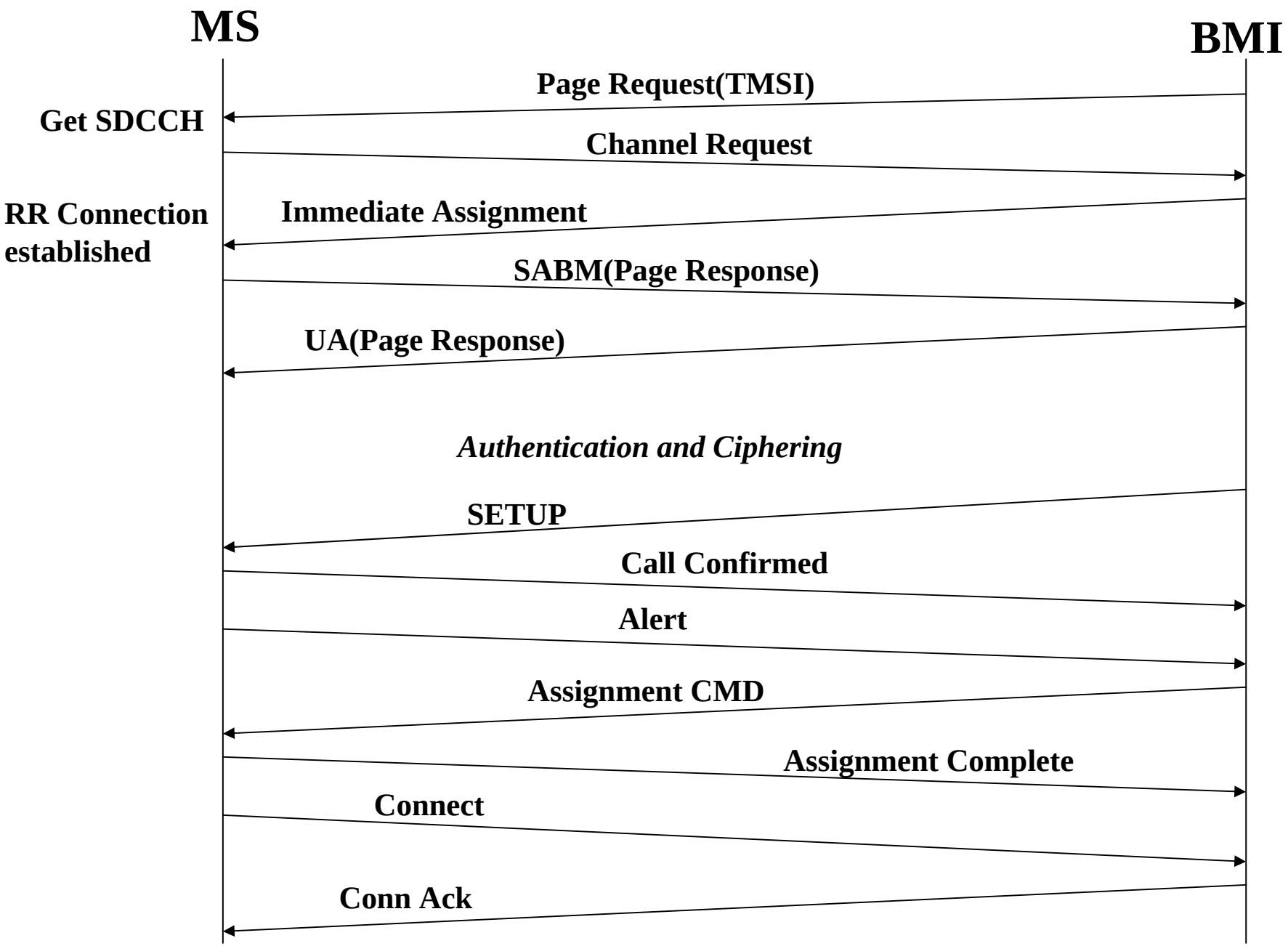
GSM Location Area(LA)Registration


Old MSC/BS
MS Home Network
New MSC/BS network
MSC
VLR
HLR
VLR
MSC
BS
MS
Registration
Loc Update
Update_location_Area
Send_Auth_Info
Ack
Authentication
Ack
Set Cipher Mode
Ack
Update_Location_Area
Cancel_Location
Ack
Insert Subscriber Data
Ack
Update_Location_Area_Accept
Registration Accept

GSM Call Termination
(call termination = call delivery)

Call termination

- 2 sets of procedure
  - Different initiators
    - BS pages MS
    - MS request channel first


MS
BMI
Page Request(TMSI)
Get SDCCH
Channel Request
RR Connection established
Immediate Assignment
SABM(Page Response)
UA(Page Response)
Authentication and Ciphering
SETUP
Call Confirmed
Alert
Assignment CMD
Assignment Complete
Connect
Conn Ack