Movilidad...

802.11

Redes inalámbricas

- Cada vez más importancia

  ofrecen: movilidad, facilidad de instalación, flexibilidad

- Evolución hacia comunicaciones inalámbricas

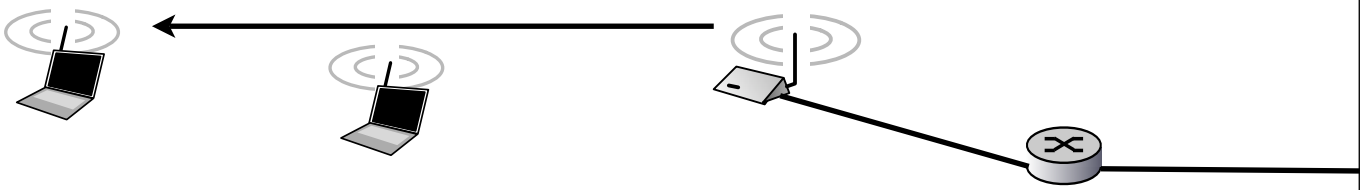
  Telefonia (GPRS,3G...), dispositivos WPAN (Bluetooth, wirelessUSB...) y **redes de datos** (802.11, WiMax?...)

- Nos centraremos en **IEEE 802.11** (vulgarmente wifi)

Wifi 802.11: Nivel físico

- NICs y puntos de acceso, transmiten y reciben señales de radio/ microondas a traves del aire
  - Varios estándares de modulación
    - DSSS, FHSS, Luz infraroja en BB (no se utiliza)
  - Y frecuencias
    - 2.4GHz, 5GHz, 3GHz

Paquete modulado sobre portadora de 2.4GHz con DSSS
La velocidad de datos en el canal es 11Mbps

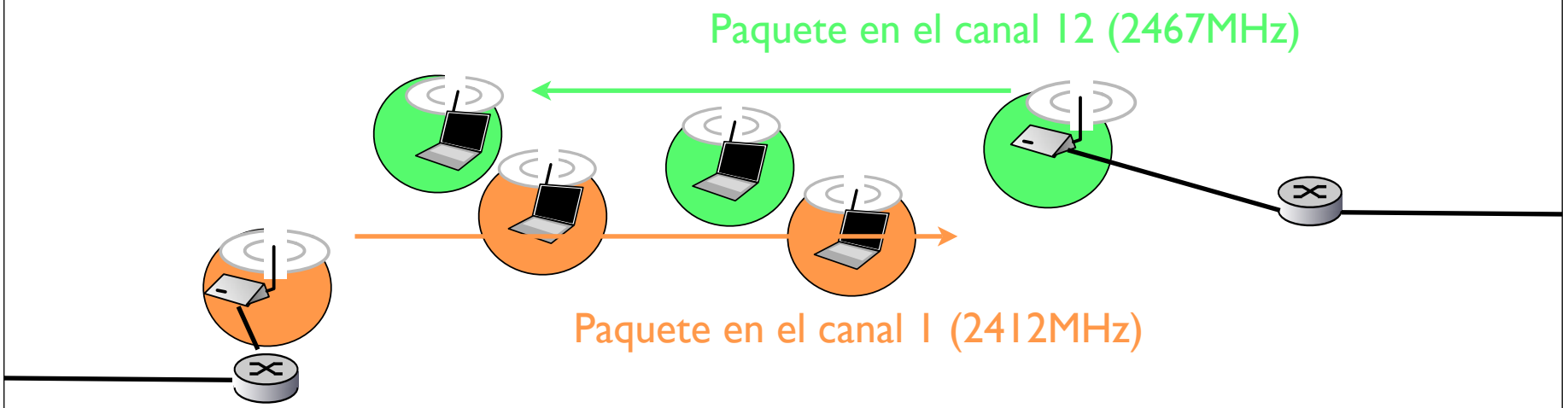


Medio compartido de broadcast
Las NICs oyen el paquete y segun la cabecera lo procesan

Wifi 802.11: Nivel físico

- Versiones con el tiempo (definidos por diferentes estandares del IEEE)
- 802.11a 5GHz velocidad de datos hasta 54Mbps
- 802.11b 2.4GHz velocidad de datos hasta 11Mbps
- 802.11g 2.4GHz velocidad de datos hasta 54Mbps
- 802.11n 2.4,5GHz velocidad de datos hasta 248Mbps
- El espectro en torno a la frecuencia utilizada se divide en varios canales utilizando frecuencias cercanas.

  Permite tener varias redes en el mismo espacio



Wifi 802.11: Nivel físico

- Canales en 802.11b
  - En la banda libre de 2.4GHz
  - Algunos son ilegales en algunos paises

    EEUU 1-11

    EMEA 1-13

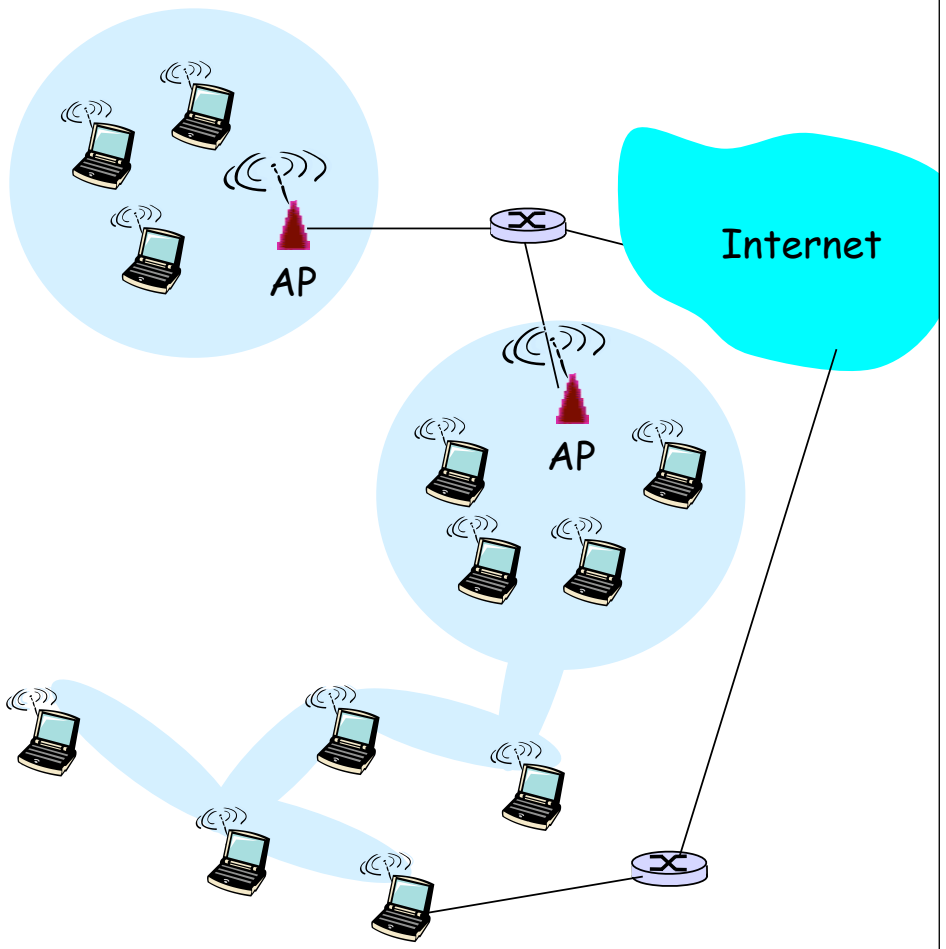
Canal	Fracuencia	Canal	Fracuencia
1	2412 MHz	8	2447 MHz
2	2417 MHz	9	2452 MHz
3	2422 MHz	10	2457 MHz
4	2427 MHz	11	2462 MHz
5	2432 MHz	12	2467 MHz
6	2437 MHz	13	2472 MHz
7	2442 MHz	14	2484 MHz

- Aún asi los canales cercanos se interfieren
- De todas formas el mecanismo de acceso al medio es capaz de soportar varias redes en el mismo canal cercanas utilizando colisiones y CSMA
- Nos interesa más el nivel de enlace

2 modos de funcionamiento

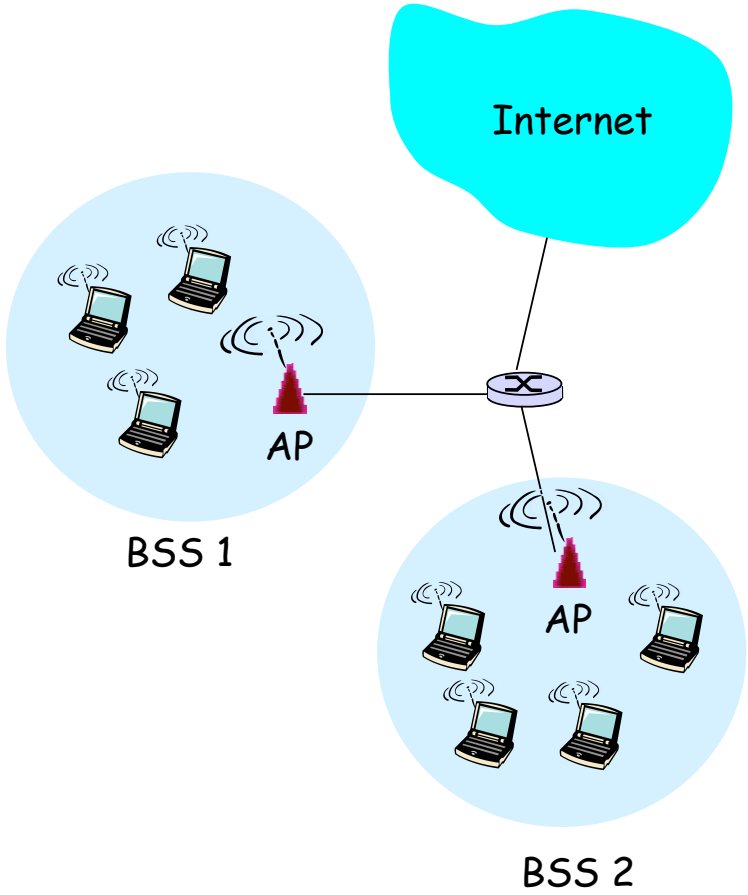
- **Base-station**
  - Infraestructura: estaciones base (access point) conectadas a una red fija
- **Ad-hoc**
  - punto-a-punto

    Los terminales inalámbricos se comunican entre si
  - Corren algoritmos de enrutamiento y extienden la red más alla del alcance de uno
  - parecido a peer-to-peer



Basic Service Set

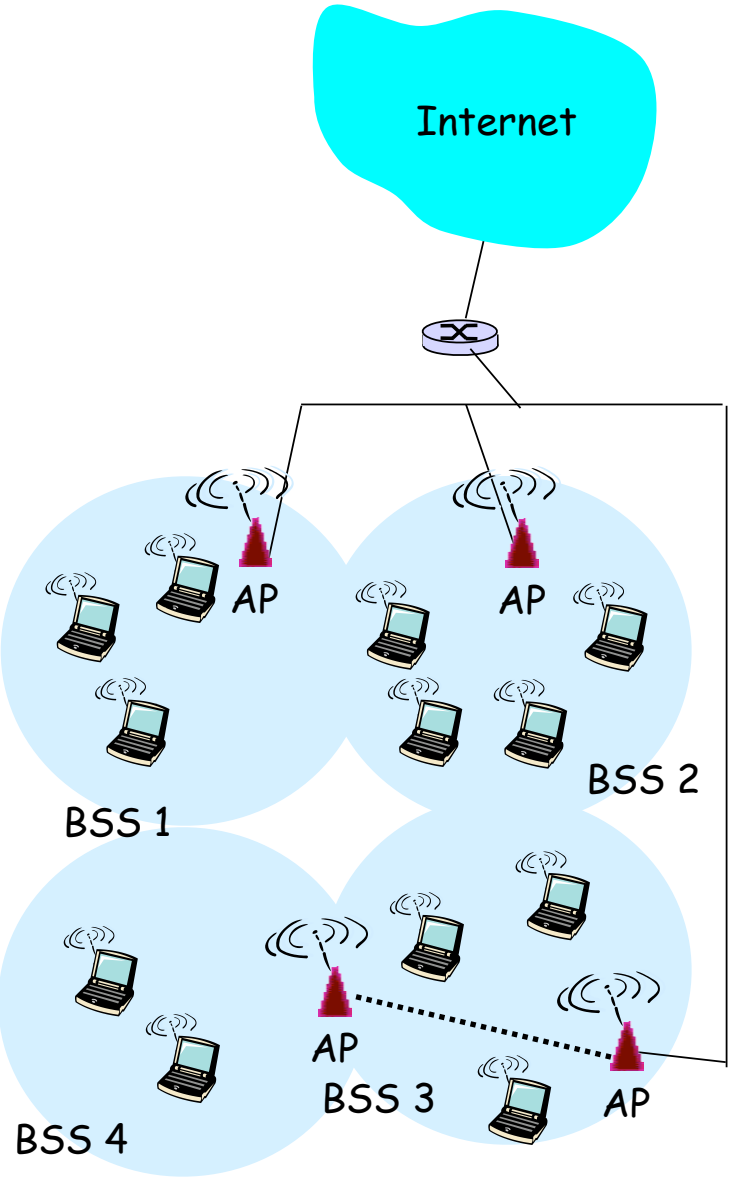
- Al conjunto formado por
  - Hosts wireless
  - 1 access point
  - su router de acceso
- Le llamaremos Basic Service Set (BSS)
- Equivalentes a las celdas de la telefonía movil



Extended Service Set

- Varios BSSs unidos para dar un servicio común en una zona mayor
- Le llamaremos Extended Service Set (ESS)
- La interconexión entre puntos de acceso puede ser por una red de cable o incluso wireless (WDS)
- El ESS tiene un identificador común de forma que el usuario no sabe si es un BSS o un ESS

  El Service Set Identifier (SSID)



802.11 Asociación

- Para poder comunicarse en un BSS los hosts deben primero asociarse a la red deseada (identificada por su SSID)
- ¿Como conocen el SSID?
  - La estación base envía periódicamente tramas (beacon) con su nombre (SSID) y su dirección MAC

    Eso permite a los hosts escanear los canales y presentar al usuario los SSIDs observados para que elija
  - La estación base no envía tramas beacon (SSID oculto) y el administrador es responsable de comunicar el SSID

    Esto a veces se ve como una medida de seguridad pero es una medida de seguridad muy ligera. El SSID no se protege y si observas el canal y ves a otro host asociarse ves el SSID

802.11 Asociación

- Antes de transmitir un host sigue los pasos:
  - Escanea permanentemente los canales en busca de tramas beacon (y los presenta al usuario para que elija o está configurado para buscar unos SSIDs que conoce)
  - Una vez elegido el SSID realiza autentificación y asociacion
    - Pide autorización al Access Point para estar en la red

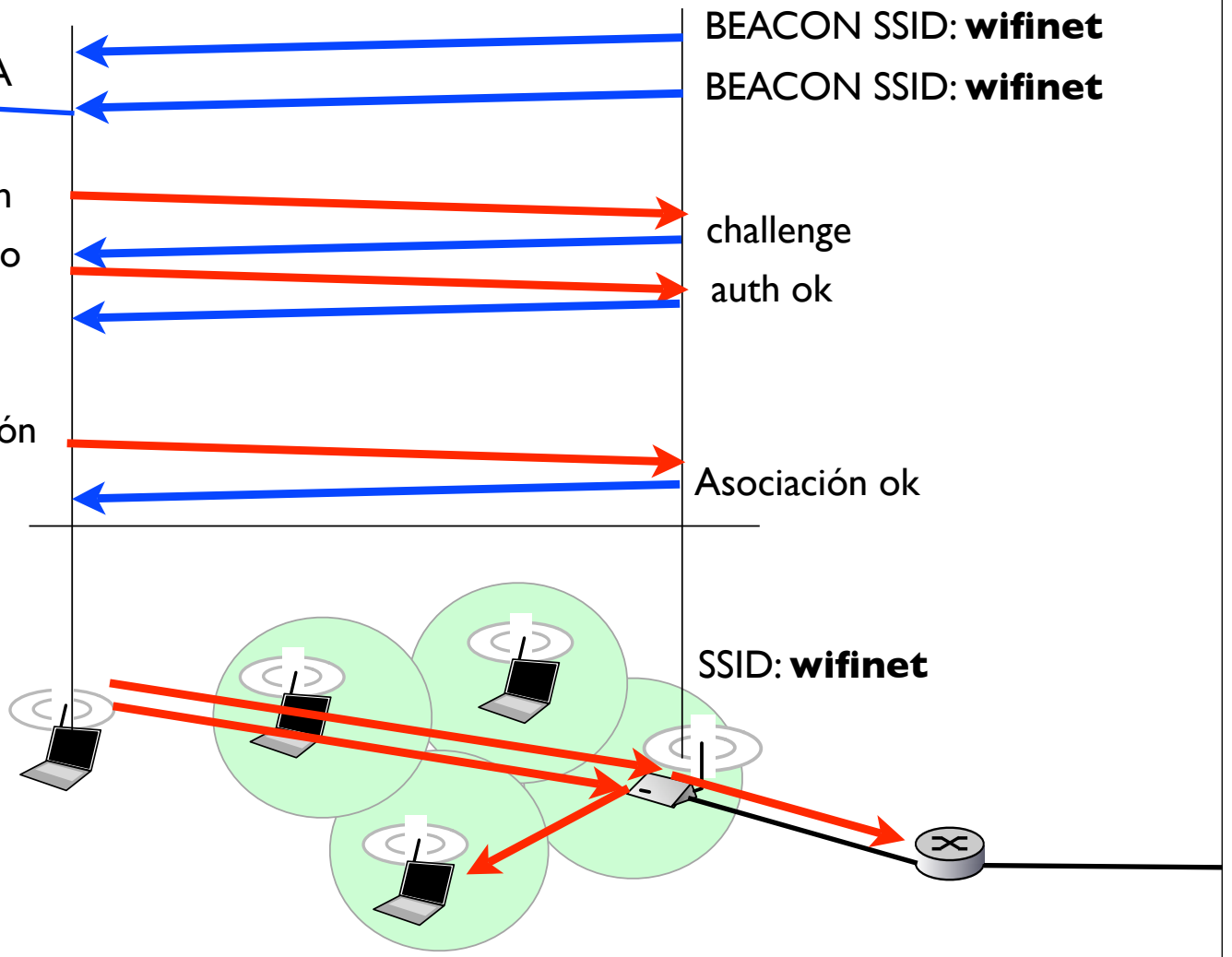
      Varios protocolos que permiten comprobar si el usuario tiene acceso a la red (con contraseña (SKA), autentificación abierta (OSA) que siempre se concede)
    - Pide al Access Point que lo considere asociado a la red

      Al completar este protocolo el host esta en el BSS
  - Una vez realizada el host forma parte del BSS y puede enviar tramas (de nivel de enlace 802.11) a otros hosts del BSS o al router.

    Normalmente lo primero que hace el host es usar protocolos de confiugracion de IP, enviar petición de DHCP para obtener IP y parámetros de configuración IP en la red de la estación

802.11 Asociación

existe una red llamada
wifinet
y usa autentificación SKA
(shared key auth)



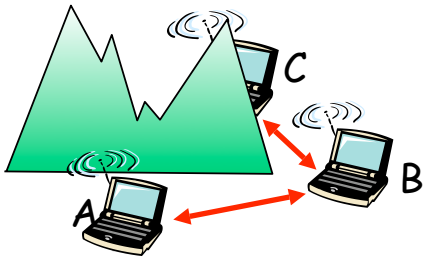
A partir de aqui puedo
enviar a los demas hosts
y al router

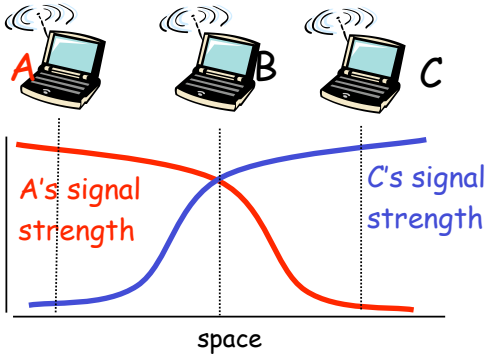
802.11 Acceso múltiple

- Acceso múltiple con problemas propios del medio inalámbrico
- Usa CSMA (carrier sense, si veo que alguien está enviando no envío)
  - No colisiona con transmisiones en curso
- Pero la detección de colisión es un problema
  - La señal se atenúa muy rápido por lo que es difícil comparar lo enviado con lo recibido. De hecho normalmente las NIC no pueden escuchar mientras envían
  - Existe el problema de terminales ocultos

    A y C no se oyen entre si

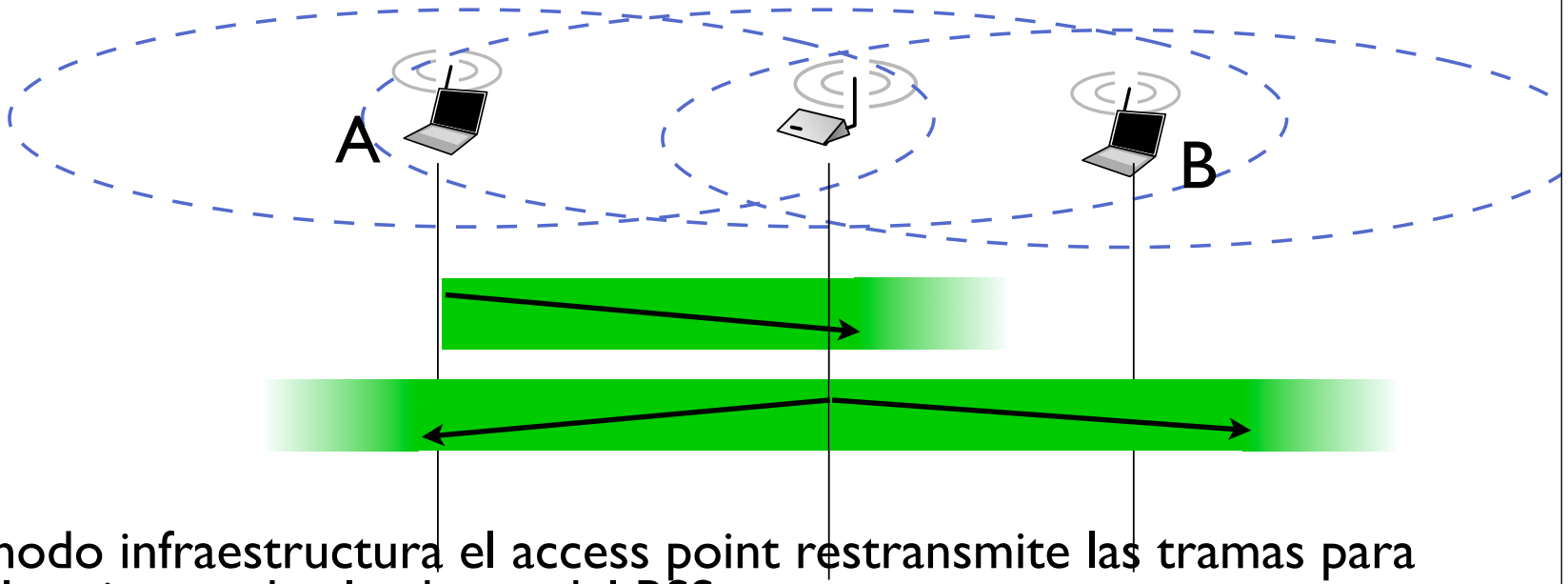
    No pueden saber que B ve una colisión





802.11 Acceso múltiple

- Problemas de potencia:
  - A oye al Access Point pero no a B

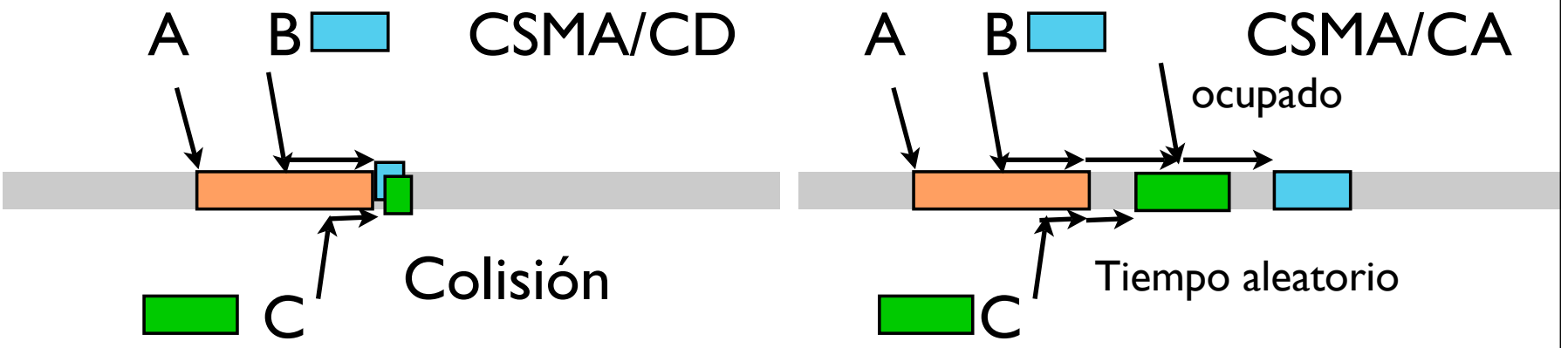


- En modo infraestructura el access point restransmite las tramas para que las oigan todos los hosts del BSS

  Las transmisiones host-host pasan siempre por el access point
- Esto no soluciona el problema del terminal oculto

CSMA/CA

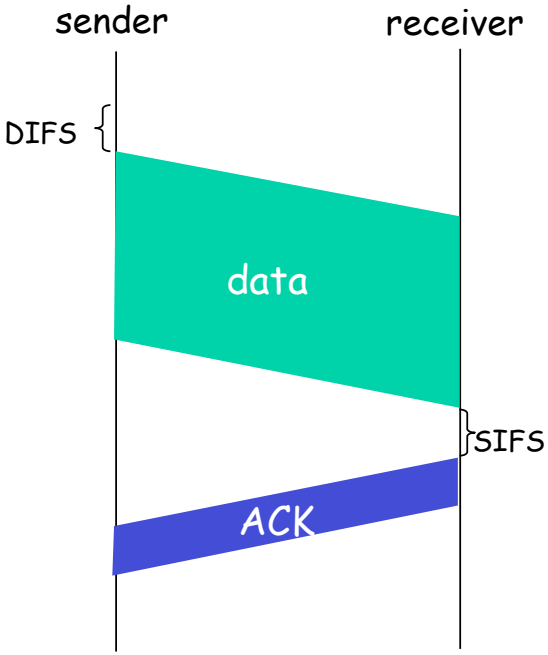
- Collision avoidance (evitación) en lugar de detección
- El receptor confirma (ACK) las tramas (ante los problemas para detectar si ha habido colisión)
- Se utilizan tiempos aleatorios cuando voy a transmitir
  - Objetivo: evitar las colisiones causadas entre las estaciones que esperan que el medio quede libre



CSMA/CA

- Emisor 802.11
  - Si el canal está vacío por un tiempo DIFS
    - Envia la trama entera (sin CD)
  - Si el canal está ocupado
    - Inicia un temporizador aleatorio (con backoff)
    - El temporizador solo descuenta tiempo con canal libre
    - Transmite cuando expire
    - Si no recibe ACK aumenta el backoff
- Receptor 802.11
  - Si recibo una trama
    - Envía ACK después de un SIFS

      (SIFS<DIFS los ACKs tienen prioridad)

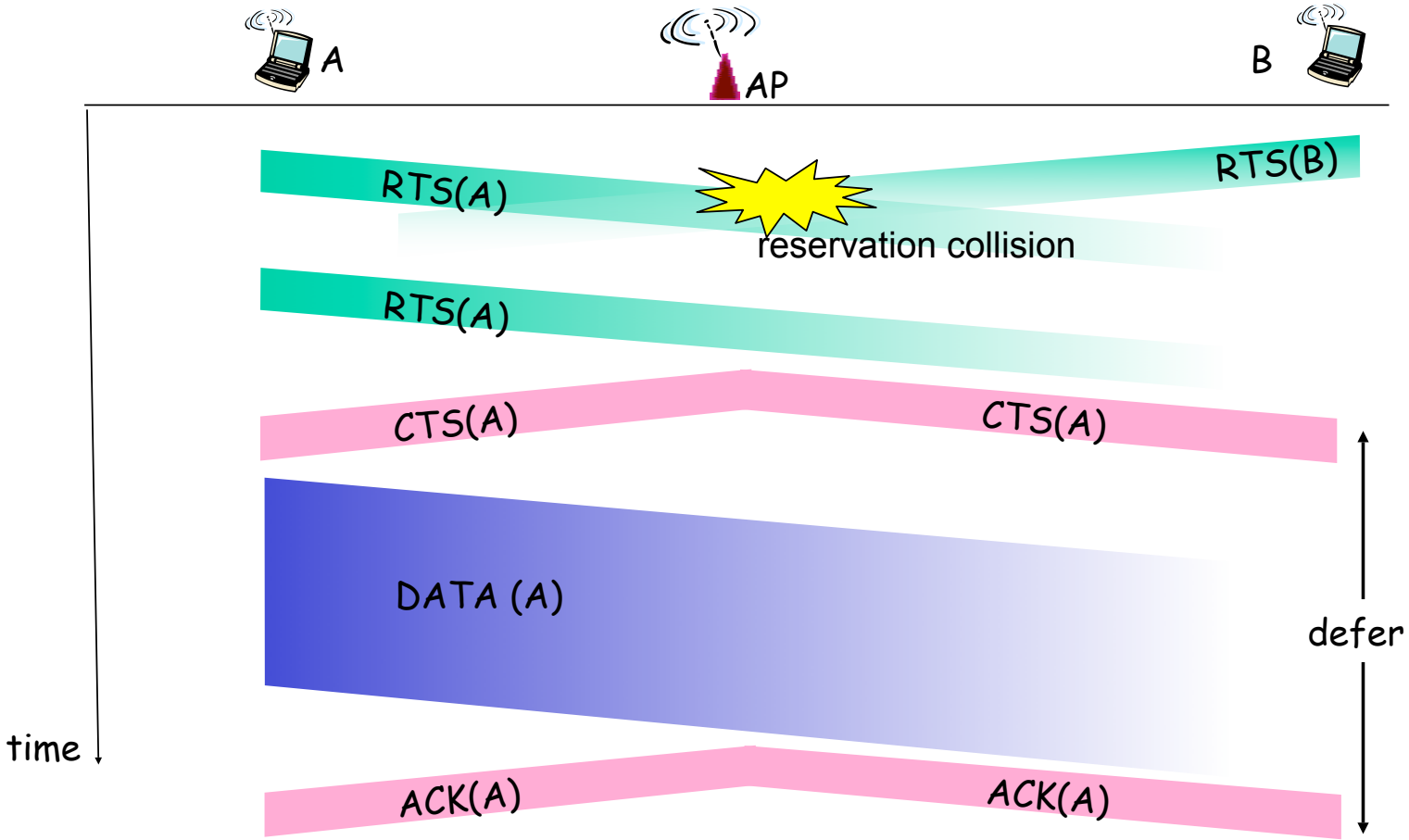


CSMA/CA

- Mejora: permitir al emisor reservar el canal para evitar colisiones en las tramas muy largas
  - El emisor envía una trama de RTS (request to send) a la estación base pidiendo el canal (usando CSMA/CA)

    Los RTS pueden colisionar con otras tramas pero al menos son cortas
  - La estación base envía el permiso en una trama CTS (Clear to send)
  - Todos los nodos reciben la CTS
    - El solicitante envia la trama
    - El resto dejan libre el canal
- Evita completamente las colisiones
  - A costa de más retardo
  - Normalmente se activa sólo para tramas por encima de una longitud

Ejemplo


A
AP
B
RTS(A)
RTS(B)
reservation collision
RTS(A)
CTS(A)
CTS(A)
DATA (A)
defer
time
ACK(A)
ACK(A)

Coordination function

- Esto es conocido como funcionamiento con funcion de coordinación distribuida

  DCF
- El estandar tambien soporta tipo polling

  Point Cordination Function (PCF)

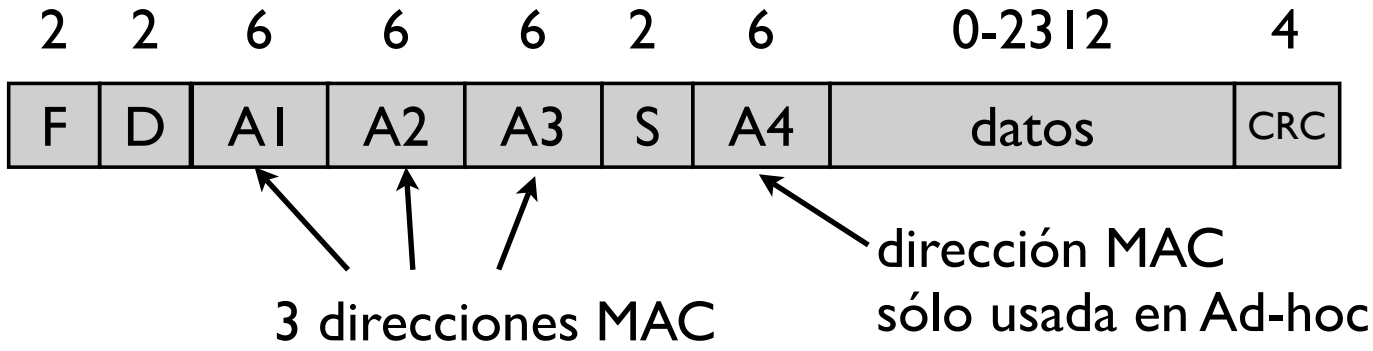
- En modo Adhoc solo se usa la DCF
- En modo infraestructura se pude usar DCF o DCF+PCF
  - Contention Free Periods (con PCF) + Contention Periods (con DCF)
- Pero PCF no se usa mucho

- 802.11e HCF Hybrid Cordination Function y soporte de QoS

Resumiendo

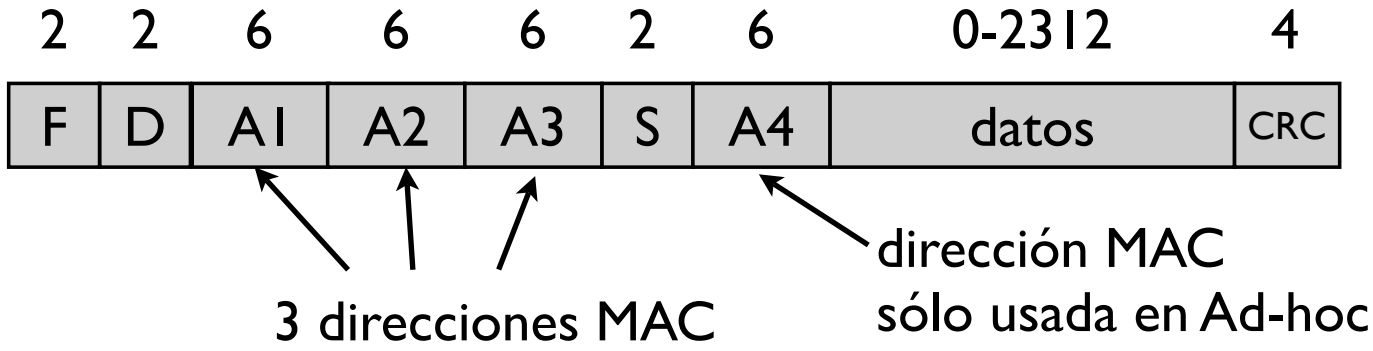
- Control de acceso al medio más complicado que en Ethernet
  - Hay ACKs en el nivel de enlace
  - Hay retransmisiones en el nivel de enlace
  - Hay autentificacion/asociacion
  - El access point retransmite tramas

802.11: formato de trama



- S: secuencia de la trama
  - necesario para el ACK
- 4 direcciones MAC
  - A1: MAC destino. Wireless host que debe recibir esta trama
  - A2: MAC origen. Wireless host que envia esta trama
  - A3: MAC router asociado al access point
  - A4: usada en modo Ad-hoc o para interconectar access-points a traves de la red inalambrica (WDS)

802.11: formato de trama



- F frame control
  - Flags y tipo de la trama (Data, ACK, RTS o CTS)
- D duración
  - Tiempo por el que se solicita el canal
    En RTS/CTS

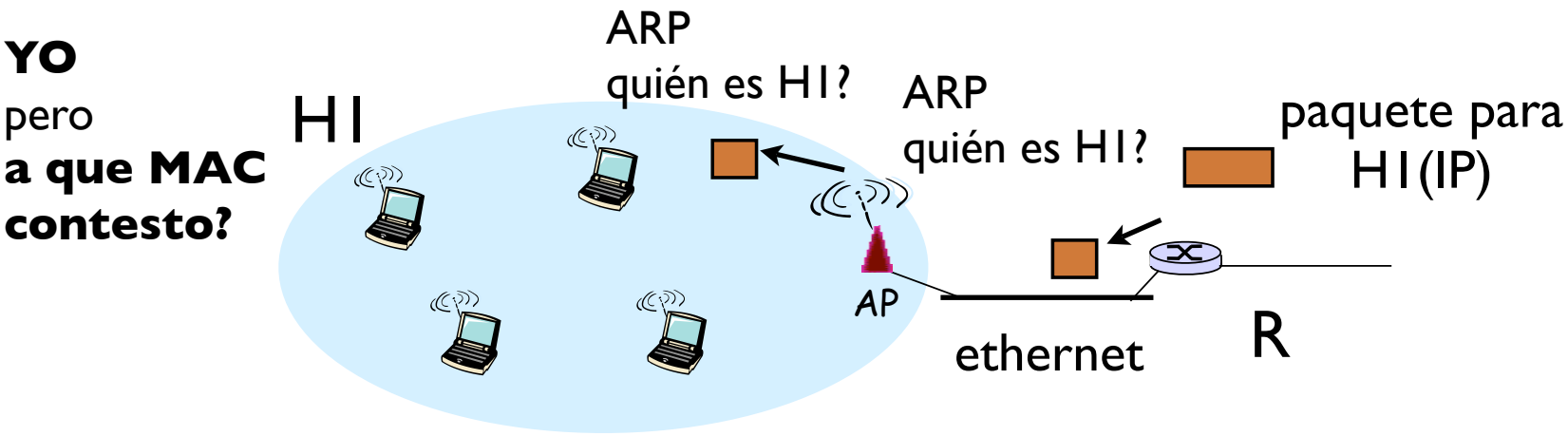
802.11 tipos de tramas

- El campo de control de la trama permite definir tipos y subtipos de tramas

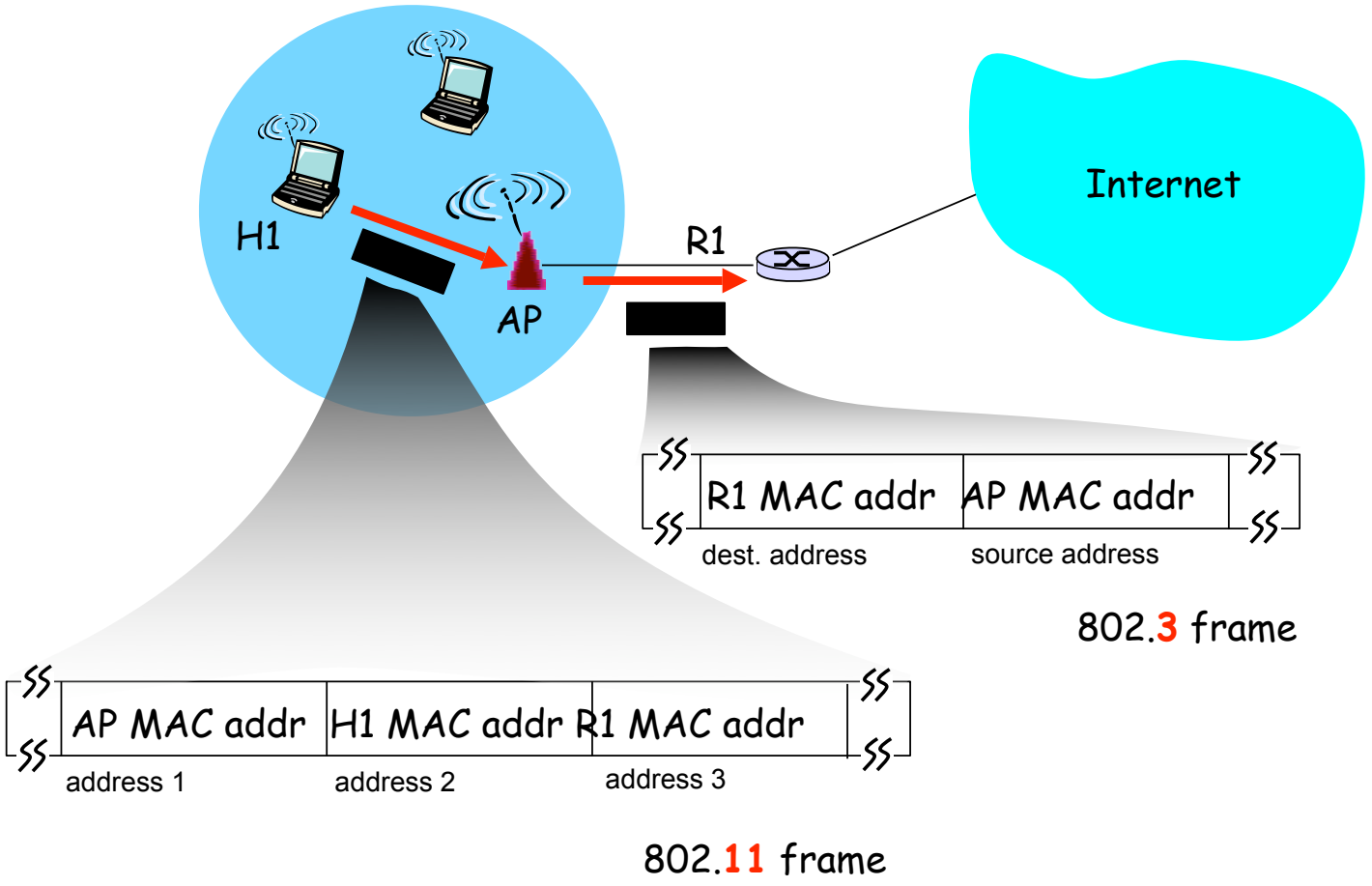
Tipo	Subtipo	Nombre
00 (Management)	0	Asociación (request)
	1	Asociación (response)
	100	Probe request
	101	Probe response
	1000	Beacon
	....	otros
01 (Control)	1011	RTS
	1100	CTS
	1101	ACK
	...	otros
10 (Datos)	0	Datos
	....	otros opciones y QoS
11 (No se usa)		

Por qué 3 direcciones?

- El access point es un dispositivo de nivel de enlace
- Para los dispositivos conectados al access point no debe haber diferencia entre hosts alámbricos o inalámbricos
- Como funcionaría el ARP aqui?



Ejemplo


H1
AP
R1
Internet
R1 MAC addr
AP MAC addr
dest. address
source address
802.3 frame
AP MAC addr
H1 MAC addr
R1 MAC addr
address 1
address 2
address 3
802.11 frame

En resumen

- Medio inalámbrico compartido
- Las redes de área local inalámbricas siguen tecnicas parecidas a las de cable
  - CSMA
  - Pero CSMA/CA en lugar de CD, colisiones costosas mejor evitar
  - Se pueden usar técnicas de reserva de canal

Seguridad en redes 802.11

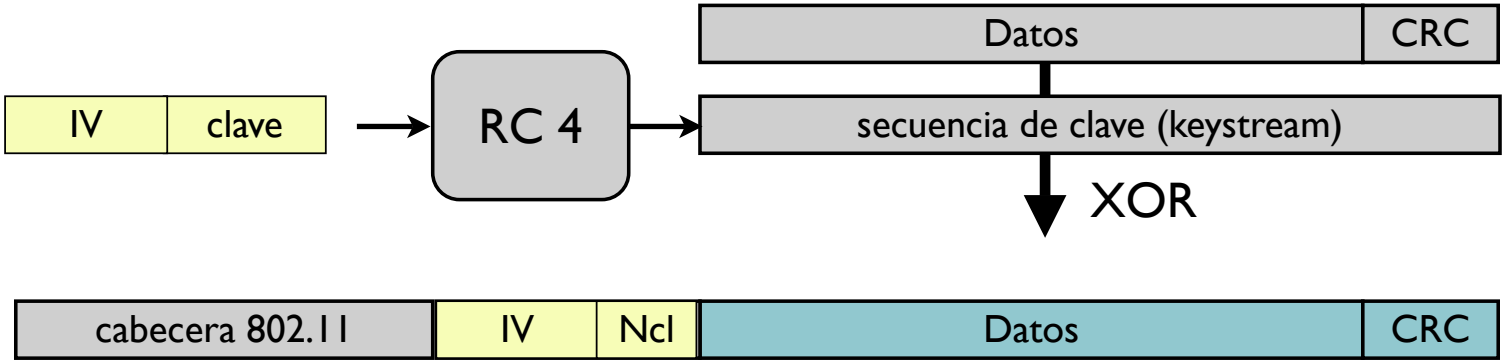
- **Wired Equivalen Privacy (WEP)**

  Conseguir en la red inalámbrica el mismo nivel de privacidad que en una de cable
- Proteger la confidencialidad de los datos que se transmiten por el aire: cifrar las tramas de datos
- Proteger la integridad de los mensajes

- Se utiliza el algoritmo de cifrado RC4

WEP

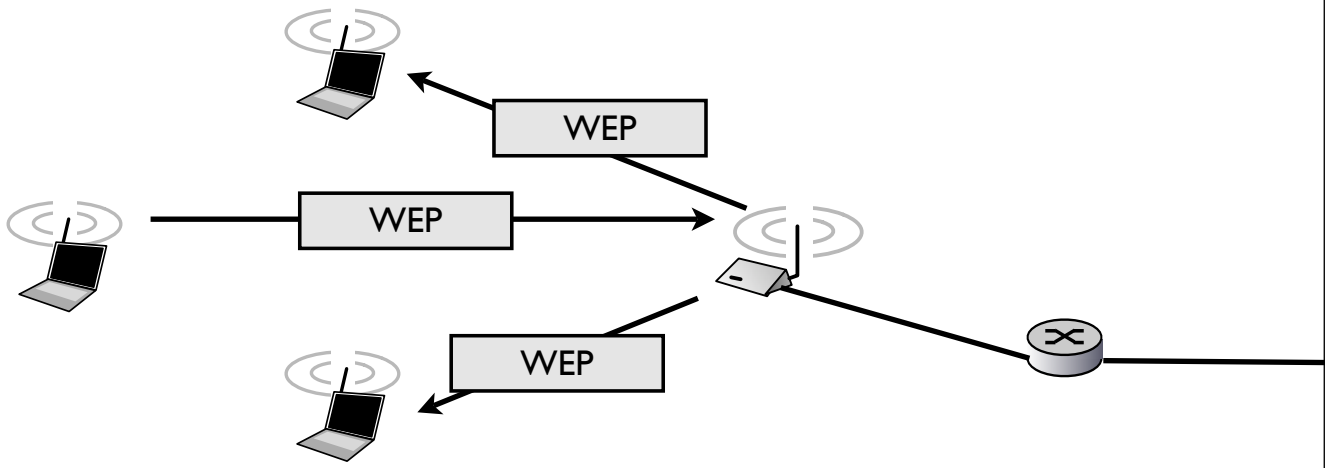
- A los datos de la trama se les añade un CRC para proteger la integridad y se cifran con RC4



- Se usan una clave de 64 o 128 bits
  - Vector de inicialización de 24 bits
  - Secreto compartido de 40 o 104 bits
- El vector de inicialización se cambia en cada paquete para cifrar cada paquete con diferente secuencia. Se envía en cada paquete para que el destinatario sea capaz de descifrar.

WEP

- Enviando con WEP
  - El terminal calcula el CRC del paquete y cifra el paquete con WEP
  - El paquete se envía al access point
  - El access point descifra el paquete y si el CRC es inválido lo tira
  - El access point puede cifrarlo con otro IV y enviarlo



- Un intruso
  - No puede descifrar los paquetes que le llegan
  - No puede generar paquetes válidos para otros

Ventajas

- Autentificación sencilla: los usuarios que conozcan la clave pueden usar la red inalámbrica
- Protección de integridad y confidencialidad "razonable"
  - o no?

Seguridad en redes 802.11

- Primer intento: **Wired Equivalen Privacy (WEP)**

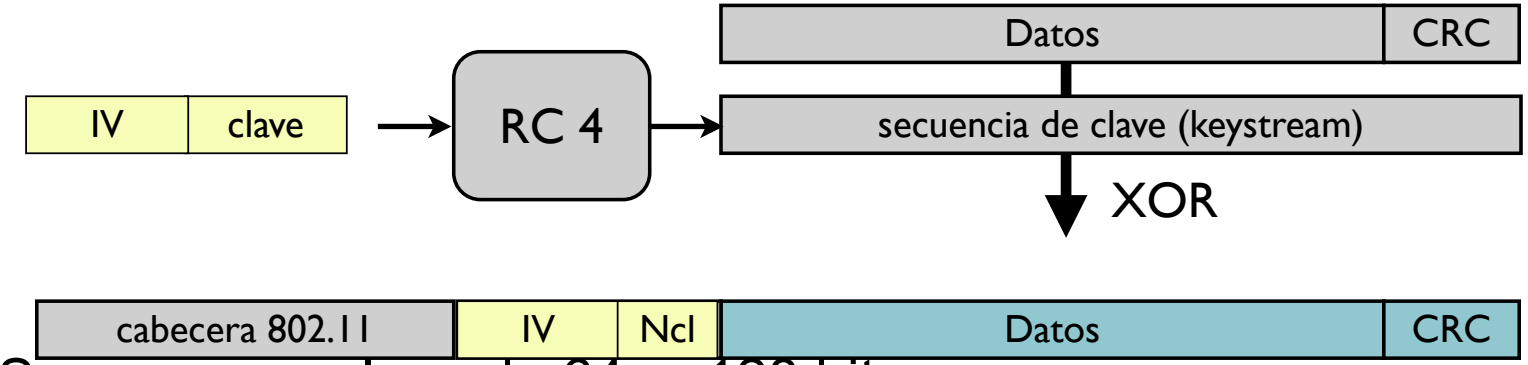
  Conseguir en la red inalámbrica el mismo nivel de privacidad que en una de cable
- Se cifran las tramas con el algoritmo RC4
  - Algoritmo de cifrado de tipo clave secreta

    Se basa en generar una serie pseudo-aleatoria a partir de la clave secreta. El mensaje se cifra con una clave de la misma longitud que el mensaje pero que depende de la clave original (intento de hacer un cifrado de Vernan)
- Originalmente era un algoritmo propietario de RCA Security
  - Pero se publicó de forma anónima en Internet y se popularizó

    El algoritmo cifra a gran velocidad y parecía muy seguro
  - Con el tiempo se le han ido encontrando algunos

WEP

- A los datos de la trama se les añade un CRC para proteger la integridad y se cifran con RC4



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Ventajas

- Autentificación sencilla: los usuarios que conozcan la clave pueden usar la red inalámbrica
- Protección de integridad y confidencialidad “razonable”
  - o no?

Desventajas

- Múltiples vulnerabilidades del sistema
  - Contra la confidencialidad
    - La clave se reutiliza. El vector de inicialización de 24 bits solo hay que esperar 16777216 paquetes para que se repita y tener dos paquetes encriptados con la misma clave
    - RC4 tiene claves debiles. Algunos IVs generan claves en las que ciertas partes de la clave secuencia dependen solo de unos pocos bits de la clave original
    - Ataques de fuerza bruta (el secreto compartido depende de una clave introducida por el usuario)
  - Contra la integridad
    - El CRC que se usa fue diseñado para detectar errores no para integridad así que no es un buen hash
    - No hay protección contra inyección de paquetes

      Si repito un paquete que veo en el canal sigue siendo un paquete valido
  - Contra la autentificación
    - Autentificación falsa
    - Ataques de desautentificación

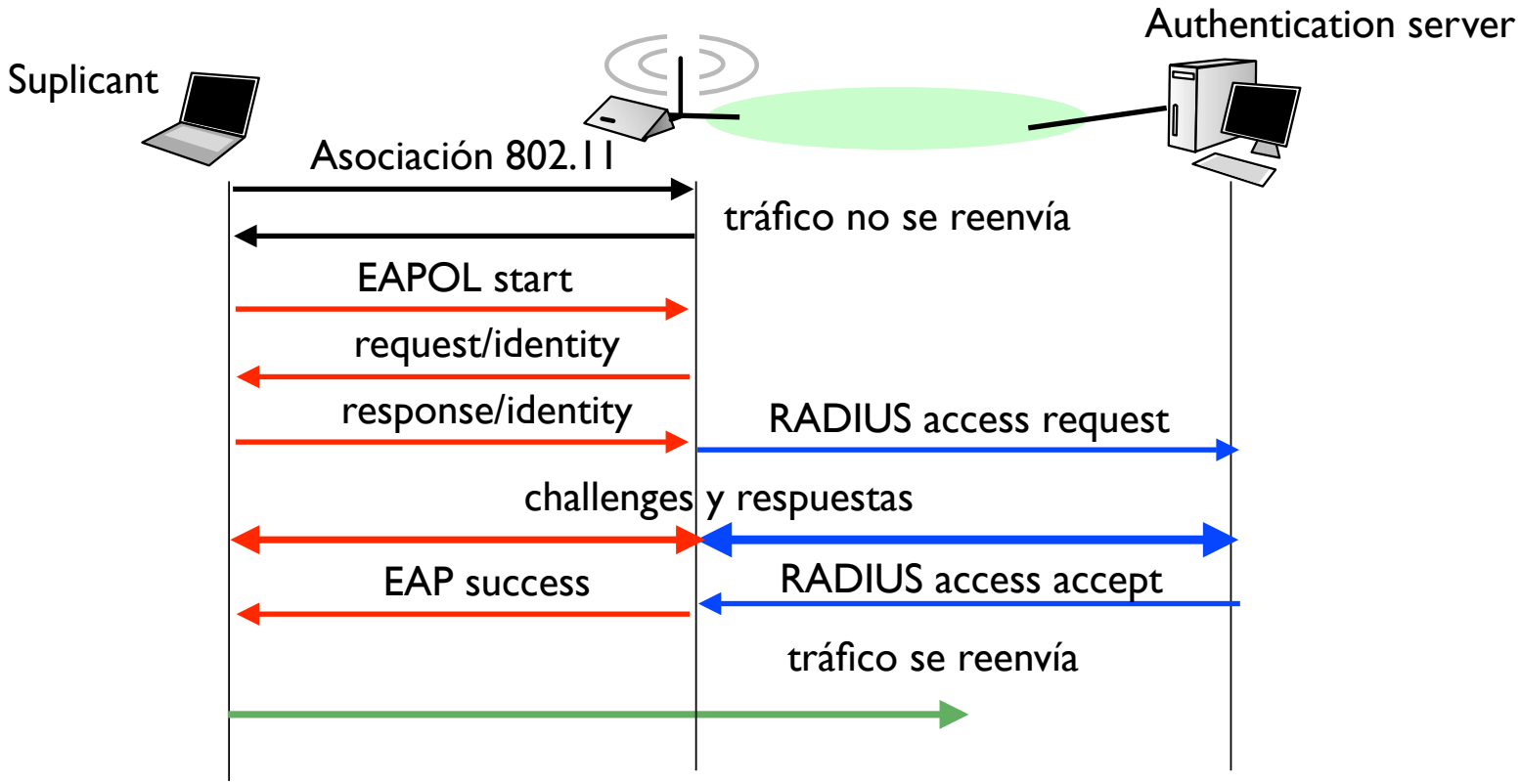
Mejorando confidencialidad de WEP

- 802.11i Estandar del IEE sobre seguridad mejorada en redes 802.11

  Añade:
- Autentificación basada en 802.1x
- 2 nuevos protocolos de cifrado para sustituir a WEP:
  - TKIP: protocolo basado en RC4 pero corrigiendo los problemas de WEP (iba a ser WEP2)

    Fácil de cambiar en hardware que ya soporte WEP
  - CCMP: protocolo completamente rediseñado para nuevo hardware, basado en AES

802.1x en inalámbricas



- Se puede usar 802.1x en una red de acceso inalámbrica
- 802.1x autentifica al usuario aunque cambie de maquina
- Acceso protegido por 802.1x no importa que se averigüe la clave WEP
  - Salvo para confidencialidad

Comercialmente

- Nombres de la WiFi alliance para los equipos reales
- **WPA (WiFi protected access)** nombre comercial de TKIP. Se definió a partir del borrador de 802.11i cuando aun se trabajaba en el standar.

  TKIP se implemento antes debido a que estaba basado en el hardware de WEP
- **WPA2** = 802.11i estandar. Con CCMP
- Ambos tienen dos formas de funcionamiento
  - **WPA personal**

    Basado en secreto compartido (las claves se calculan a partir de una clave definida en los BSS y en los PCs)
  - **WPA enterprise**

    Clave basada en TLS y certificados

Es WPA suficiente?

- Es mucho más difícil de atacar aunque hay propuestas de ataques basados en fuerza bruta
- En WPA personal sigue pudiéndose hacer ataques de diccionario a la autentificación
- Se siguen pudiendo hacer ataques de bajo nivel
  - Inundación de paquetes de deautentificación o desasociación
  - Robo de ancho de banda
  - Denegación de servicio por Jamming/interferencia

Ad-hoc

Redes Adhoc

- Mobile Ad-hoc Networks (MANET)
  - Red formada entre dispositivos inalambricos moviles para la ocasion
    - Enlaces inalambricos
    - Alta movilidad
    - Cuestiones de ahorro de potencia... los dispositivos usan baterias
- WMN wireless mesh networks
  - Red de bajo coste basada en enrutamiento cooperativo sobre un backbone inalambrico
    - Enlaces inalambricos
    - Movilidad reducida (o solo de una parte de los dispositivos)
    - Los dispositivos tienen alimentación eléctrica

      (y entonces por que no tienen red de cable?)

Enlaces Ad-hoc

- Enlaces 802.11 de tipo Ad-hoc
  - punto a punto o multipunto
  - IP configurada

  - No asociacion?
  - Solo DCF
  - No access point

Enrutamiento en redes Adhoc

- Position aware
  - Protocolos que hacen uso de la posicion geográfica
  - Enviar a los vecinos más o menos en la dirección del destino

- Position unaware
  - Como los protocolos de enrutamiento tradicionales
  - vecinos y grafo sin significado geografico

Position-unaware Routing

Position-unaware Routing Protocols can be classified based on the way a
protocol tries to find a route to a destination:

- Proactive Routing Protocol
- Reactive Routing Protocol

Proactive Routing

- Entire network topology is known to all nodes and maintained in a routing table
- Since each node knows the complete topology, a node can immediately find the best route to a destination.
- Routing messages are exchanged among the nodes periodically to update their routing tables
  - Routing Table Advertising

Protocols:

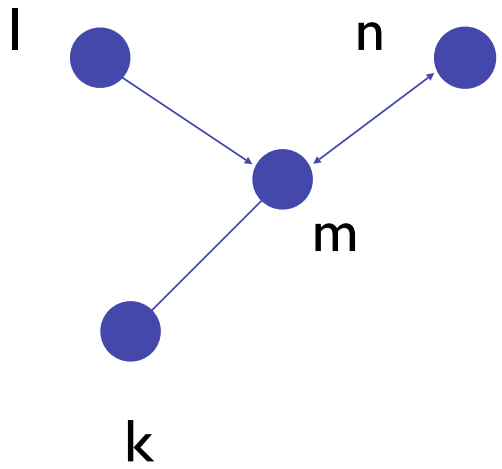
- Destination-Sequenced Distance Vector (DSDV)
- Fisheye State Routing (FSR)
- ...

Destination-Sequenced Distance Vector Protocol

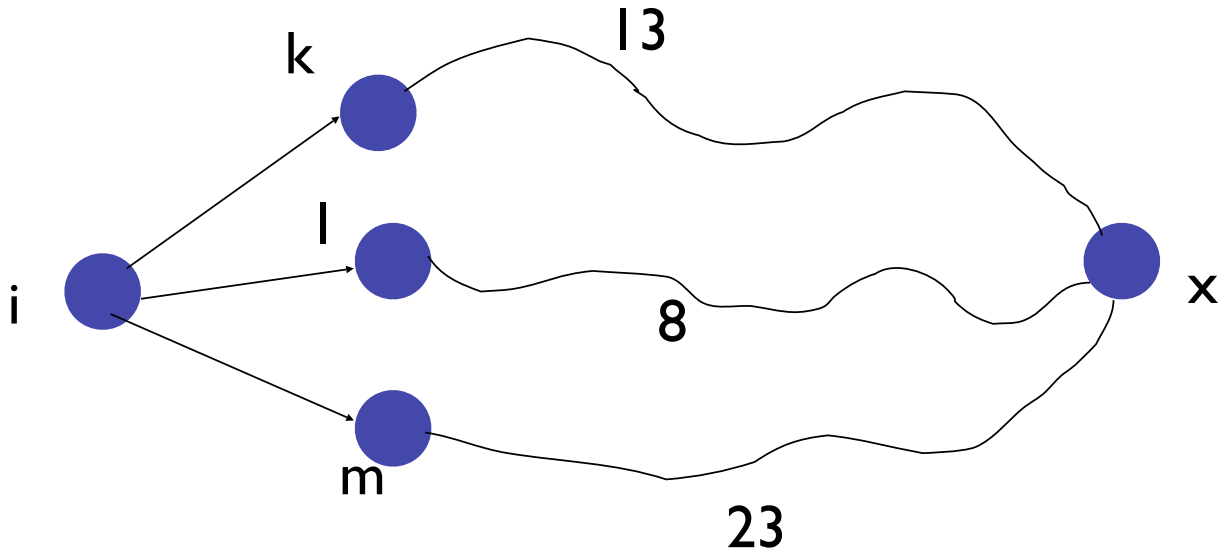
- Packets are transmitted between the nodes using route tables stored at each node.
- Each route table lists all available destinations and the number of hops to each destination.
- For each destination, a node knows which of its neighbours leads to the shortest path to the destination.

Routing Table Entries

- The destination's address
- Next Hop to Destination
- The number of hops to the destination
- The sequence number of the information received from that destination. This is the original sequence number assigned by the destination.



How the local Routing Table is Used



- Consider a node i. Suppose, i needs to send a message to node x.
- i can look up the best route to x from its routing table and forwards the message to the neighbour along the best route.
- The neighbour in turn checks the best route from its own table and forwards the message to its appropriate neighbour. The routing progresses this way.

Routing Table Advertising

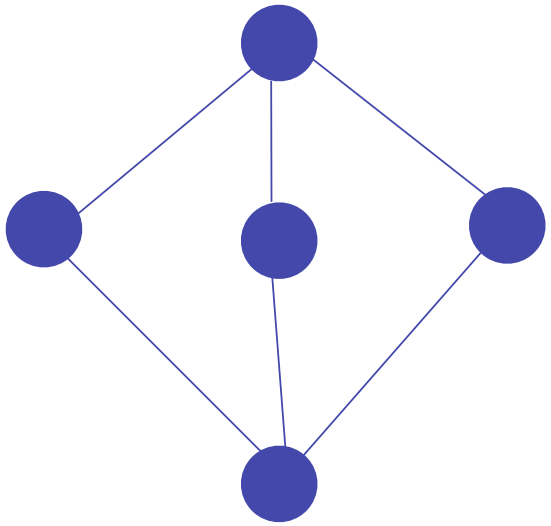
- The DSDV protocol requires each mobile node to advertise its own route table to all of its current neighbours.
- Each mobile node agrees to forward route advertising messages from other mobile nodes.
- This forwarding is necessary to send the advertisement messages all over the network.
- In other words, route advertisement messages help mobile nodes to get an overall picture of the topology of the network.

Responding to Topology Changes

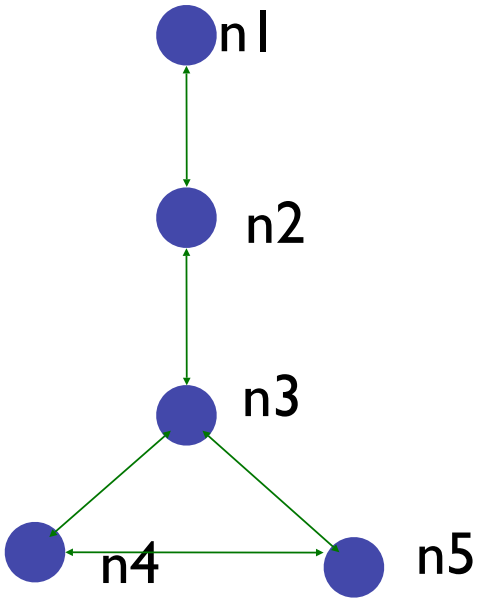
- It is necessary to avoid excessive control traffic (route update information). Otherwise, the bandwidth will be taken up by control traffic.
- The solution is to broadcast two types of updates:
  - Full Dump / Incremental Dump
- A full dump carries complete routing tables. A node broadcasts a full dump infrequently.
- An incremental dump carries minor changes in the routing table. This information contains changes since the last full dump.
- When the size of an incremental dump becomes too large, a full dump is preferred.

Responding to Topology Changes

- When a node i receives incremental dump or full dump from another node j, the following actions are taken :
  - The sequence number of the current dump from j is compared with previous dumps from j
  - If the sequence number is new, the route table at i is updated with this new information. (Reason for Sequence number: Loops)
  - Node i now broadcasts its new route table as an incremental or a full dump.



An Example of Route Update



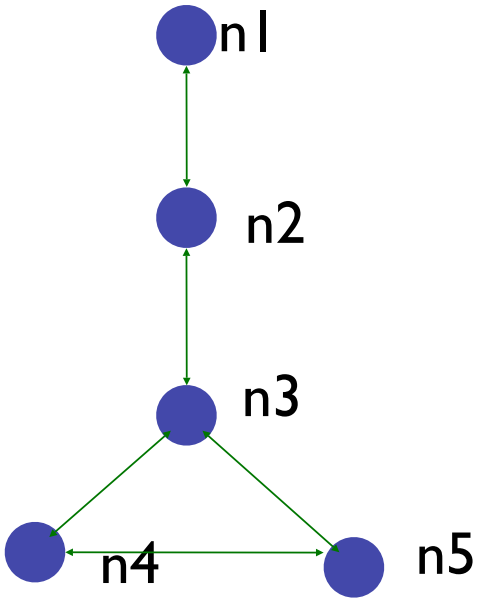
- At the start, each node gets route updates only from its neighbours.
- For n4, the distances to the other nodes are :

n5=1, n3=1, n2= ∞

n1 = ∞

All nodes broadcast with a sequence number 1

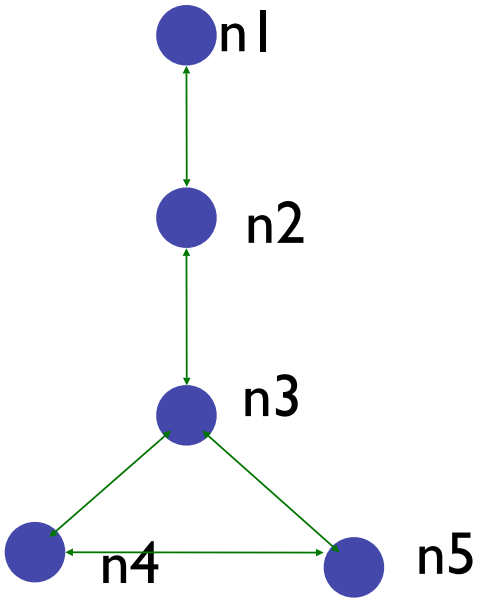
An Example of Route Update



- After this, nodes forward messages that they have received earlier.
- The message that n2 sent to n3 is now forwarded by n3
- For n4, the distances are now :
  n5=1, n3=1, n2=2, n1= ∞

All messages have sequence number 1

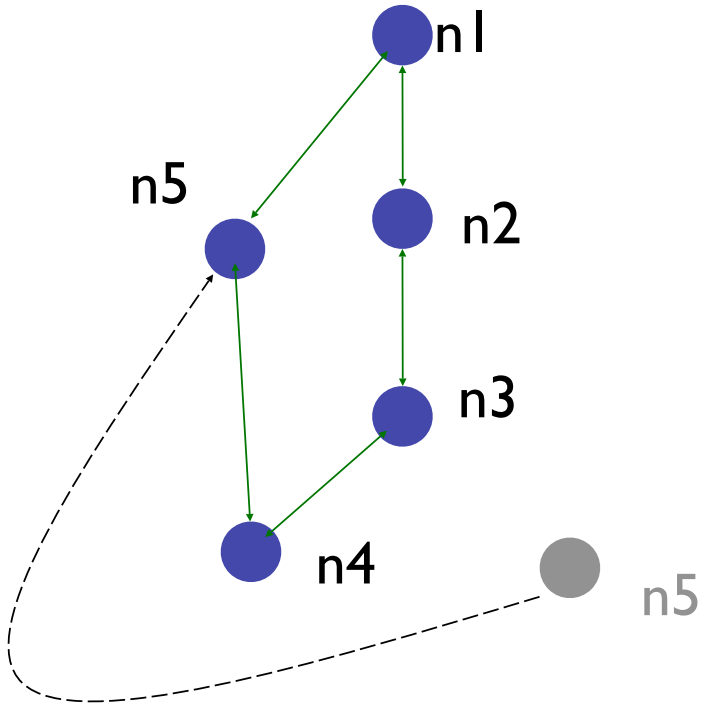
An Example of Route Update



- Finally, after second round of forwarding, n4 gets the following distances :

  n5=1, n3=1, n2=2, n1=3

An Example of Route Update



- Suppose n5 has moved to its new location.
- Also, n5 receives a new message from n1 with a sequence number 2
- This message is forwarded by n5 to n4
- Two distances to n1 in n4
- Distance 3 with sequence number 1, and
- Distance 2 with sequence number 2
- Since the latter message has a more recent sequence number, n4 will update the distance to n1 as 2

How good is DSDV?

- DSDV is an efficient protocol for route discovery. Whenever a route to a new destination is required, it already exists at the source.
- Hence, latency for route discovery is very low.
- However, DSDV needs to send a lot of control messages. These messages are important for maintaining the network topology at each node.
- This may generate high volume of traffic for high-density and highly mobile networks.

Reactive Routing

- In a reactive protocol, a route is discovered only on-demand, when it is necessary.
- These protocols generate much less control traffic at the cost of latency, i.e., it usually takes more time to find a route compared to a proactive protocol.

Protocols:

- Dynamic Source Routing (DSR)
- Ad Hoc On-Demand Distance-Vector (AODV)
- ...

Dynamic Source Routing

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- Each node maintains a route cache to remember routes that it has learnt about.

- A node may store multiple routes to a destination in its route cache.

- A node can react to changes in network topology much more rapidly by taking advantage of cached routes.

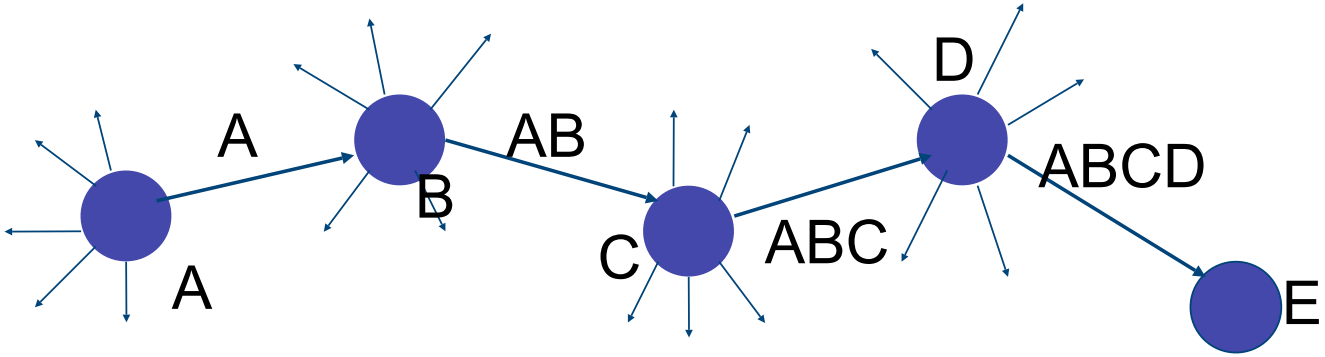
- For example, if one route to a destination is broken, the source node can choose another route to the destination from its route cache.

Route Discovery

- The DSR protocol has two important mechanisms through which the protocol operates.
  - Route Discovery: A node A wishing to send a packet to node E obtains a route to E
    - Route Request
    - Route Reply
  - Route Maintenance: When A is using a discovered route to E, A may detect that the route is broken. In such cases, A may use an alternate route to E (if it is known), or start another route discovery phase to E.

Route Discovery

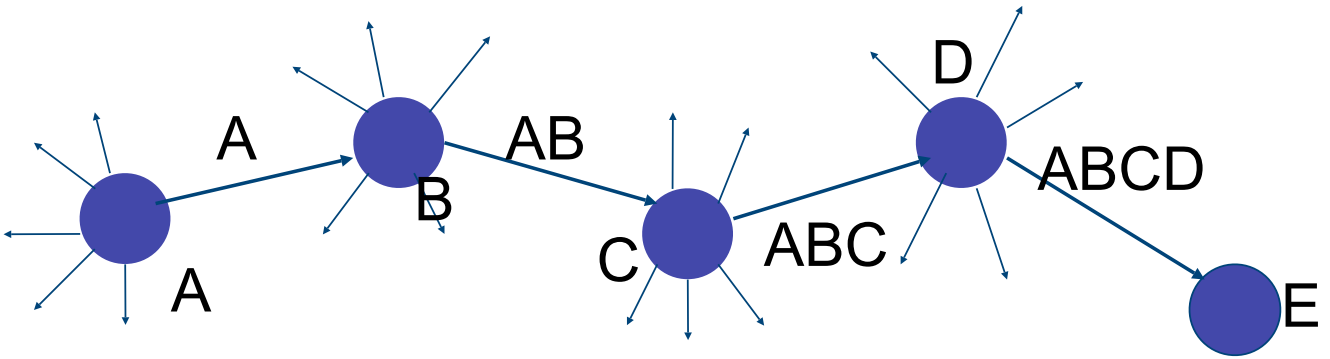
- Node A is trying to discover a route to node E.
- A broadcasts a route request message to its neighbours. This message is received by all nodes within the transmission range of A.
- Each route request message contains the source and target of the route discovery.
- Also, each route request is stamped with an unique ID assigned by the source.



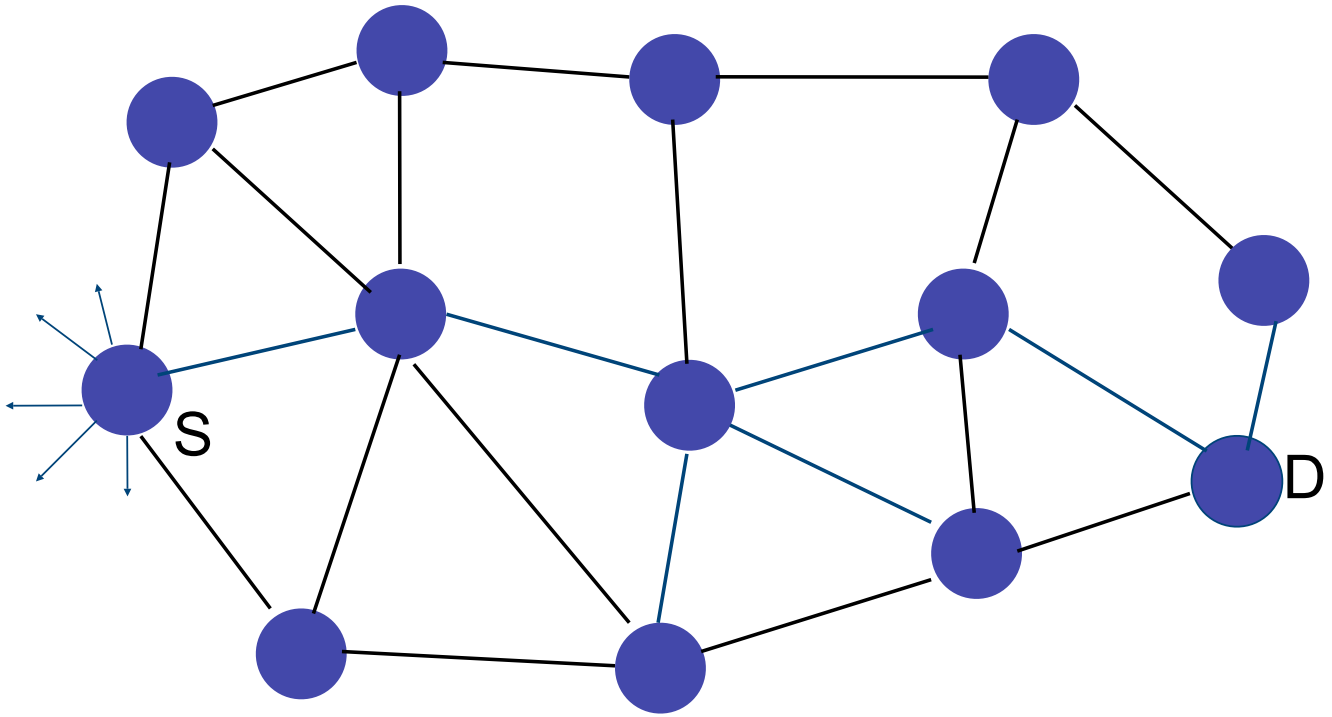
Route Discovery

Every node that receives a route request message, does one of the following:

- Check the unique ID of route request; already received: discard RReq
- A node like C first searches its route cache to see whether it has a stored route to E. If it has such a route, C sends that route to A. (Route Reply)
- If there is no such route in its route cache, C broadcasts the route request message to its neighbours. C attaches its own ID to the route request message



Example



Route Maintenance

- The DSR protocol has two important mechanisms through which the protocol operates.
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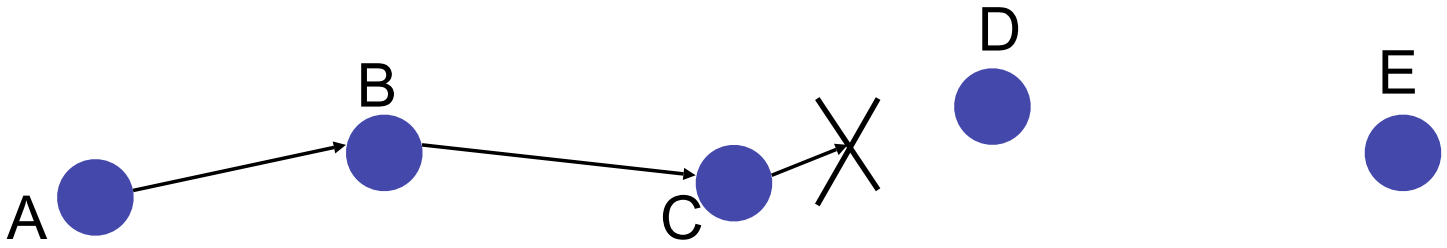
  - Route Maintenance: When A is using a discovered route to E, A may detect that the route is broken. In such cases, A may use an alternate route to E (if it is known), or start another route discovery phase to E.

Route Error



• A node like C tries to forward the message and waits for acknowledgment. C will retransmit the message a fixed number of times if no acknowledgment arrives.

• After that, C will initiate a route error message.

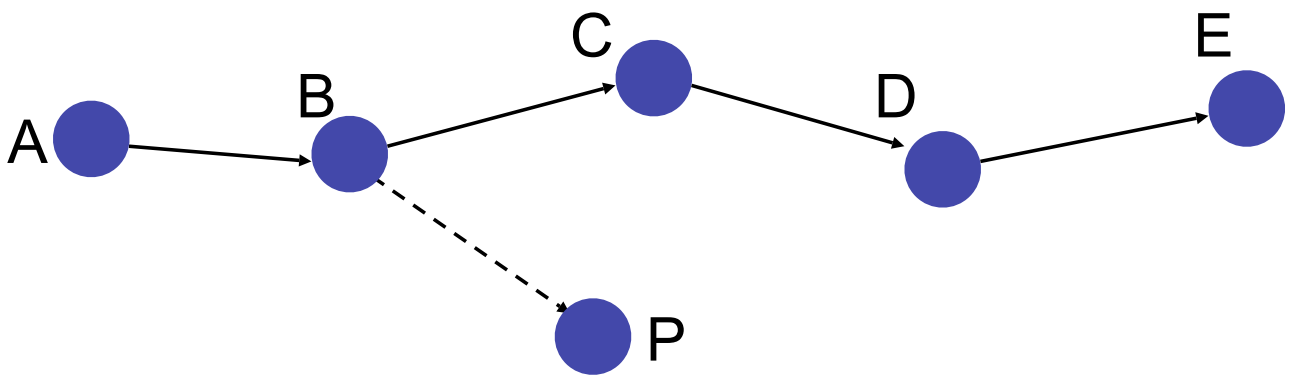
• In this example, C will initiate a route error message back to A indicating that the link to D is currently broken.

• A will remove this route from its route cache and try another route to E, if it has one. Or, A may start a new route discovery.

Caching Overheard Routing Information

• DSR extensively takes advantage of existing knowledge of the network topology.

• Each node gathers information about the network topology by overhearing other nodes' transmissions.

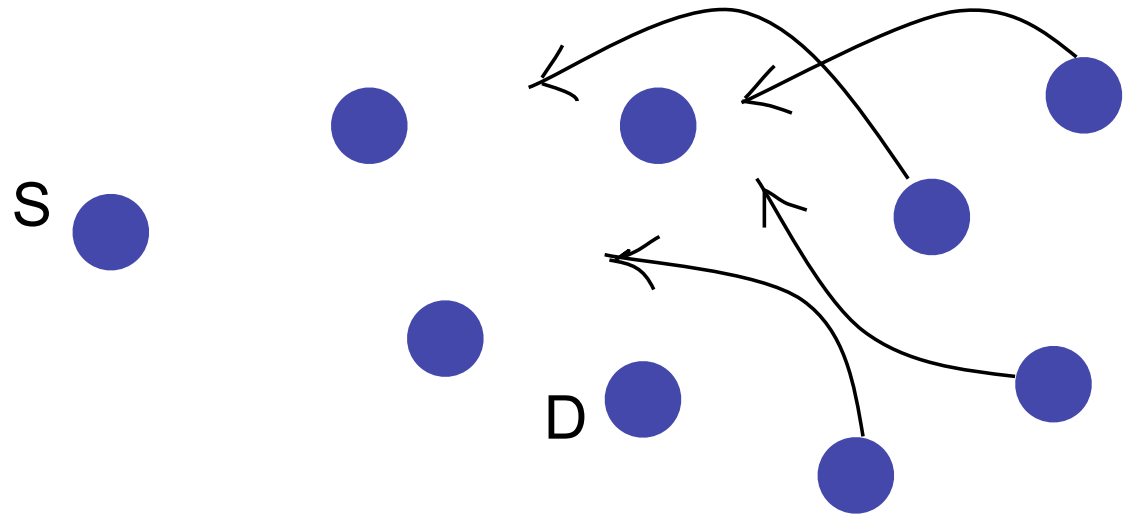


Route Request Hop Limit

• Sometime it is not good to propagate a route request message throughout the network.

• In case D is in the neighbourhood of S, the route request message from S should not propagate too far away.

• If D is near S, propagating the route request message too far will result in too many unnecessary route reply messages in future.



Restricted Propagation of Route Request

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• A better strategy is to propagate route request messages with increasing hop count.

• Initially, send the route request to a distance of 2 hops. If no route reply is received after sometime, send the route request to a distance of 4 hops and so on.

• This reduces network congestion by reducing the number of route reply messages.

Non-uniform Packet Size in DSR

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- When a source node A sends a packet to a destination node E, A should send the entire route to E along with the packet.

- This is necessary for the intermediate nodes to forward the packet.

- Usually all media support packets of uniform size. If a packet is large, it has to be split into smaller packets.

- This may cause problems in the wireless medium as packets that are split into smaller parts may not arrive in correct order.

- Intermediate nodes may not be able to forward packets correctly.

Ad-Hoc On-Demand Distance-Vector (AODV)

Table-Driven

- Routing Tables (for saving information about topology)

On-Demand

- Route Discovery
  - Expanding Ring Search (Route Request Type)
  - Forward Path Setup (Saving Route Information in R'Tables)
- Route Maintenance (Methods to repair broken links)

Routing Tables

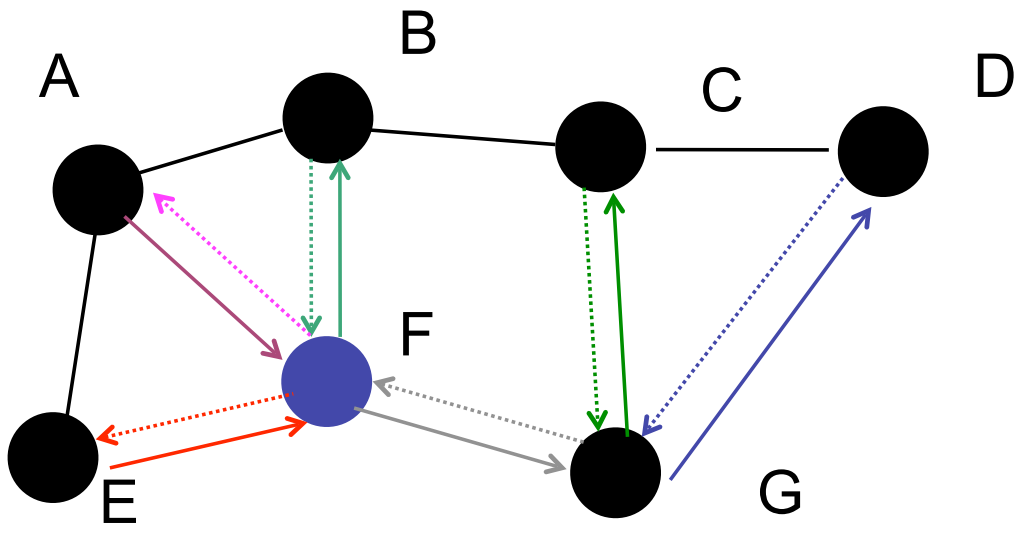
Entries:

- Destination IP
- Next Hop IP
- Destination Sequence Number
- Life Time
- List of Precursors
- Hop Count Number

Sequence Number:

The Seq. Number is monotonically increased each time the node learns of a change in the topology.

Example (Routing Table)



Routing Table of Node F:

Dest. IP	Next Hop IP	Dest. SeqNo.	Lifetime	Precursors	Hop Count
B	B	2	10	E	1
C	G	4	6	E	2
D	G	4	8	A, E	2

Route Discovery

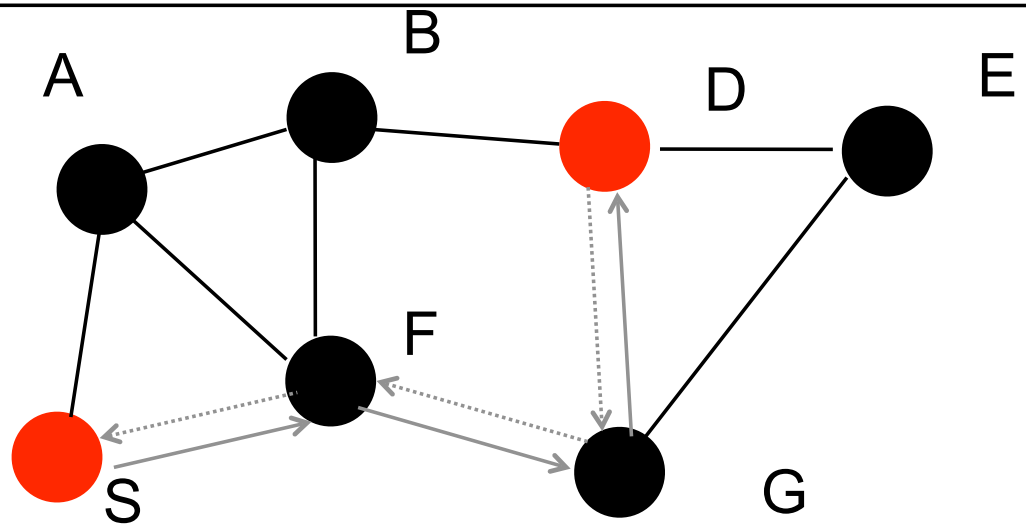
Like DSR, we use two types of messages, route request (RREQ) and route reply (RREP):

- Route Request Messages (RREQ)
- Route Request Processing (RREQ)
  - Reverse Route Entry
- Expanding Ring Search (RREQ)
- Responding to Route Request Messages (RREP)
  - Forward Path Setup

Route Request Message

- When node S wants to send a message to node D, S searches its routing table for a valid route to D.
- If there is no valid route, S initiates a RREQ message with the following components :
  - The IP addresses of S and D
  - The current sequence number of S and the last known sequence number of D
  - A broadcast ID from S. This broadcast ID is incremented each time S initiates a RREQ message.
  - Hop count
- The <broadcast ID, IP address> pair of the source S forms a unique identifier for the RREQ.

Example (Routing Request Message)



Routing Table of Node S:

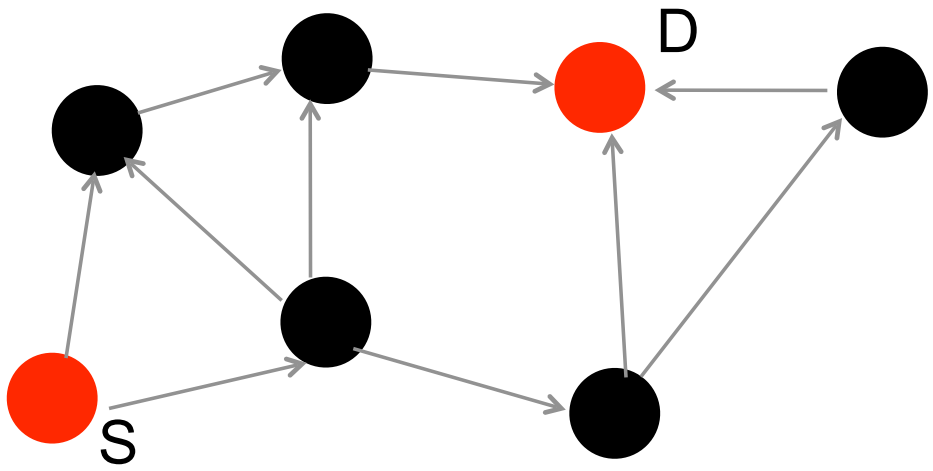
Dest. IP	Next Hop IP	Dest. SeqNo.	Lifetime	Precursors	Hop Count
D	**F**	**4**	**0**		**3**

Routing Request Message:

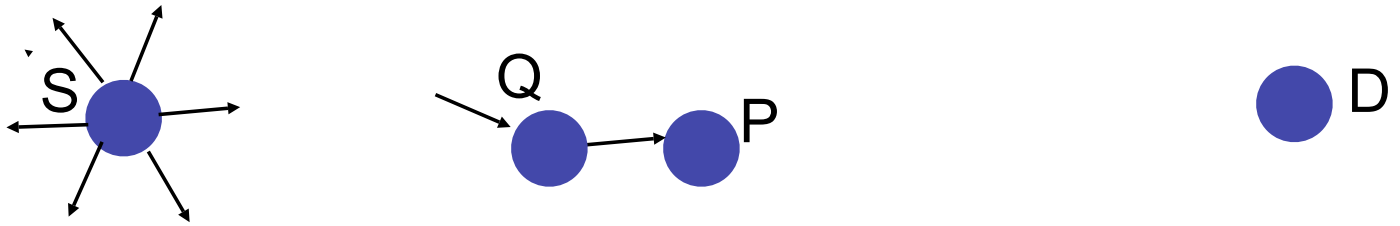
Source IP	Dest. IP	Source Seq. No.	Dest. Seq. No.	Broadcast ID	Hop Count
S	**D**	**7**	**4**	**15**	**0**

Route Request Processing

- Suppose a node P receives the RREQ from S. P first checks whether it has received this RREQ before.
- Each node stores the <broadcast ID, IPaddress> pairs for all the recent RREQs it has received. (for a specific amount of time)

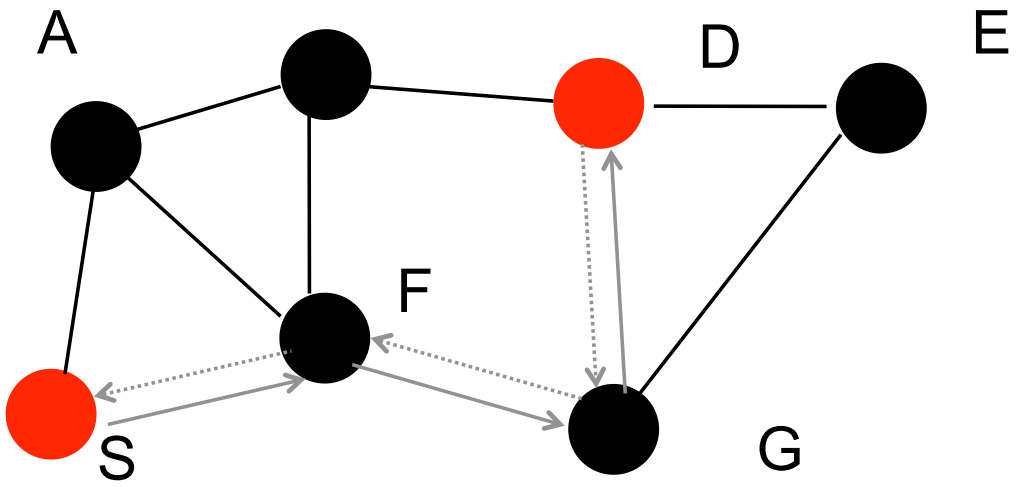


Processing a RREQ Message



- If P has seen this RREQ from S already, P discards the RREQ. Otherwise, P processes the RREQ :
  - P sets up a reverse route entry in its routing table for the source S.
  - This entry contains the IP address and current sequence number of S, number of hops to S and the address of the neighbour from whom P got the RREQ.

Reverse Route Entry



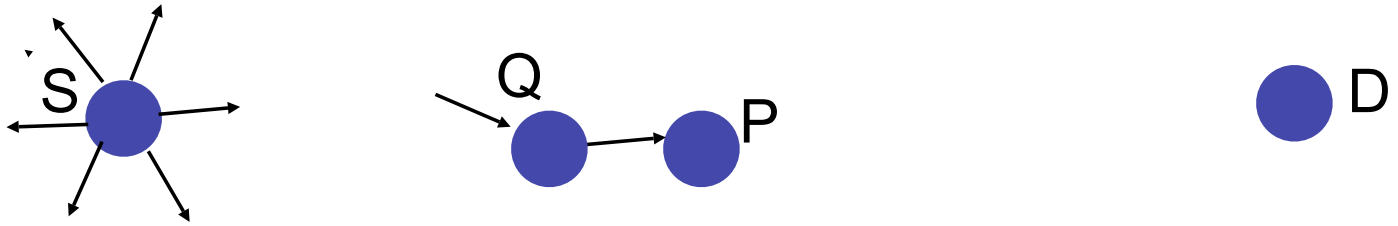
Routing Table of Node G:

Dest. IP	Next Hop IP	Dest. SeqNo.	Lifetime	Precursors	Hop Count
S	**F**	**7**	**10**		**2**

~~Routing Request Message:~~

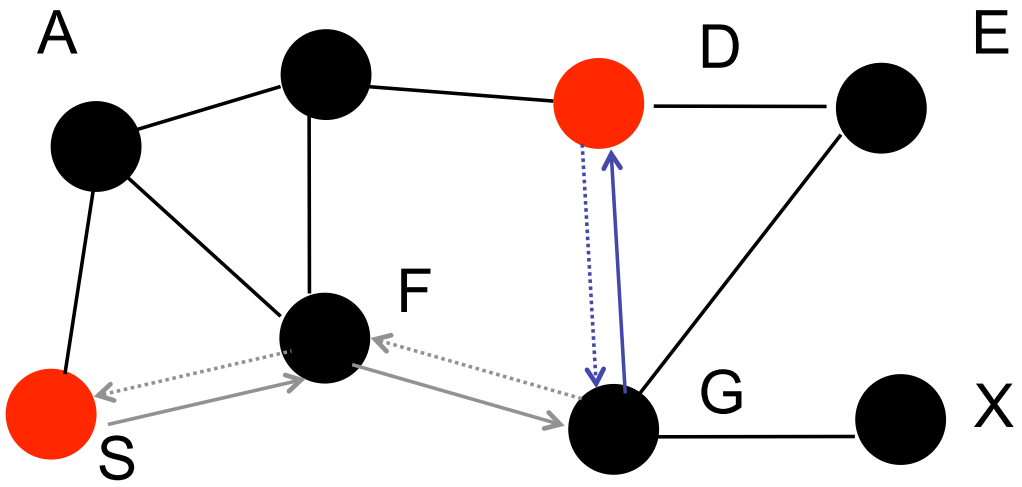
Source IP	Dest. IP	Source Seq. No.	Dest. Seq. No.	Broadcast ID	Hop count
S	**D**	**7**	**4**	**15**	**2**

Responding to a RREQ Message



- P can respond to the RREQ from S if P has an unexpired entry for D in its routing table.
- Moreover, the sequence number from D that P has, must not be less than the sequence number of D that was in the RREQ from S.
- This ensures that there is no loop in the route.
- If P satisfies both of these requirements, it sends a RREP message back to S.
- If P cannot reply to the RREQ from S,
- P increments the hop-count of the RREQ and broadcasts it to its neighbours.

Responding to a RREQ Message



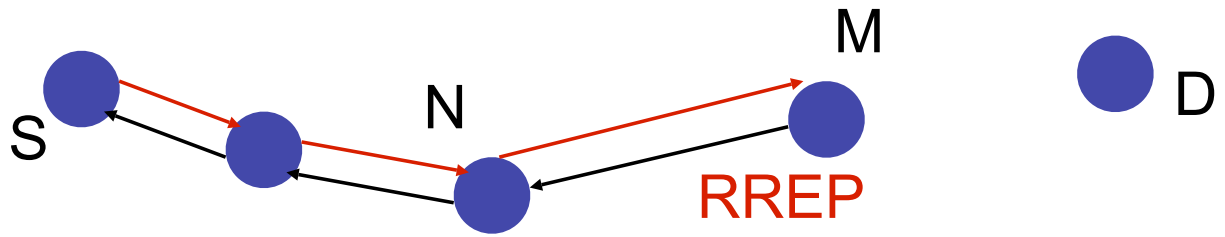
Routing Table of Node G:

Dest. IP	Next Hop IP	Dest. SeqNo.	Lifetime	Precursors	Hop Count
D	**D**	**6**	**10**	**X**	**1**

~~Routing Request Message:~~

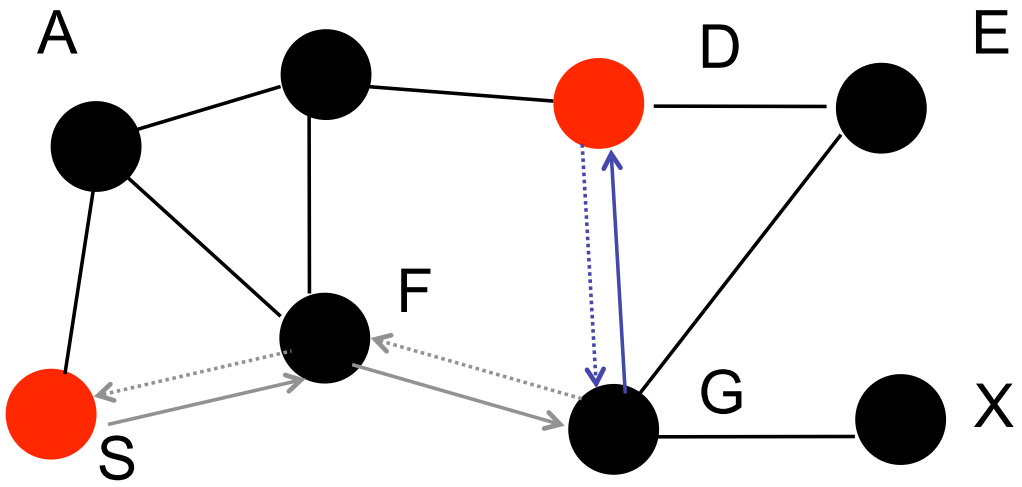
Source IP	Dest. IP	Source Seq. No.	Dest. Seq. No.	Broadcast ID	Hop Count
S	**D**	**7**	**4**	**15**	**2**

Forward Path Setup (Sending a RREP)



- A RREP message has several fields :
  - The IP address of both source and destination
  - If the destination is sending the RREP, it sends its current sequence number, a lifetime for the route and sets the hop-count to 0
  - If an intermediate node is responding, it sends the last known sequence number from the destination, sets the hop-count equal to distance from the destination and a lifetime for the route.

Responding to a RREP Message



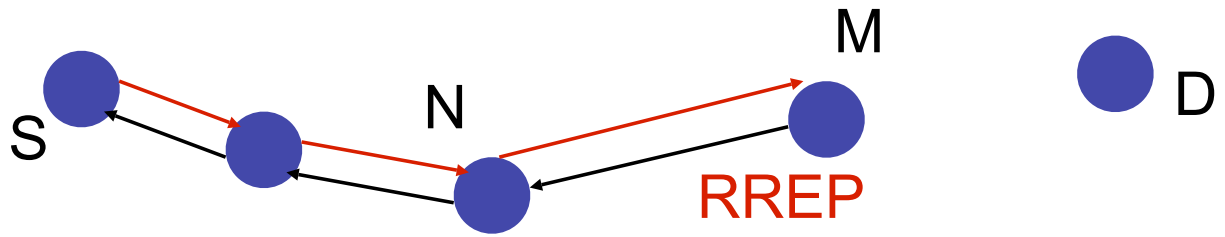
Routing Table of Node G:

Dest. IP	Next Hop IP	Dest. SeqNo.	Lifetime	Precursors	Hop Count
D	**D**	**6**	**4**	**X**	**1**

~~Routing Reply Message:~~

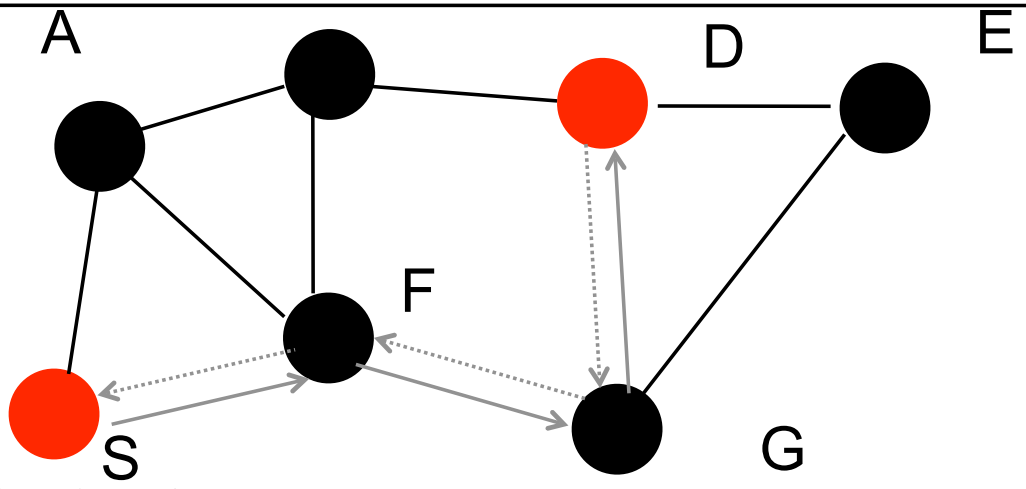
Source IP	Dest. IP	Source Seq. No.	Dest. Seq. No.	Lifetime	Hop Count
S	**D**	**7**	**6**	**4**	**1**

Forward Path Setup



- A node (here Node M) sends a RREP back to a neighbour from whom it received the RREQ.
- When an intermediate node (here Node N) receives a RREP, it sets up a forward path to the destination in its route table.
- This contains the IP addresses of the neighbour and the destination, hop-count to the destination and a lifetime for the route.

Forward Path Setup



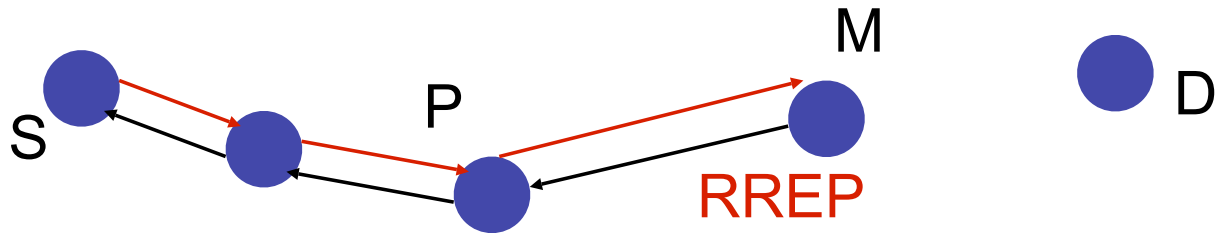
Routing Table of Node F:

Dest. IP	Next Hop IP	Dest.Seq. No	Lifetime	Precursors	Hop Count
S	**S**	**7**	**10**	**G**	**1**
D	**G**	**6**	**4**	**S**	**2**

Routing Reply Message:

Source IP	Dest. IP	Source Seq. No.	Dest. Seq. No.	Lifetime	Hop Count
S	**D**	**7**	**6**	**4**	**1**

Handling more than one RREP

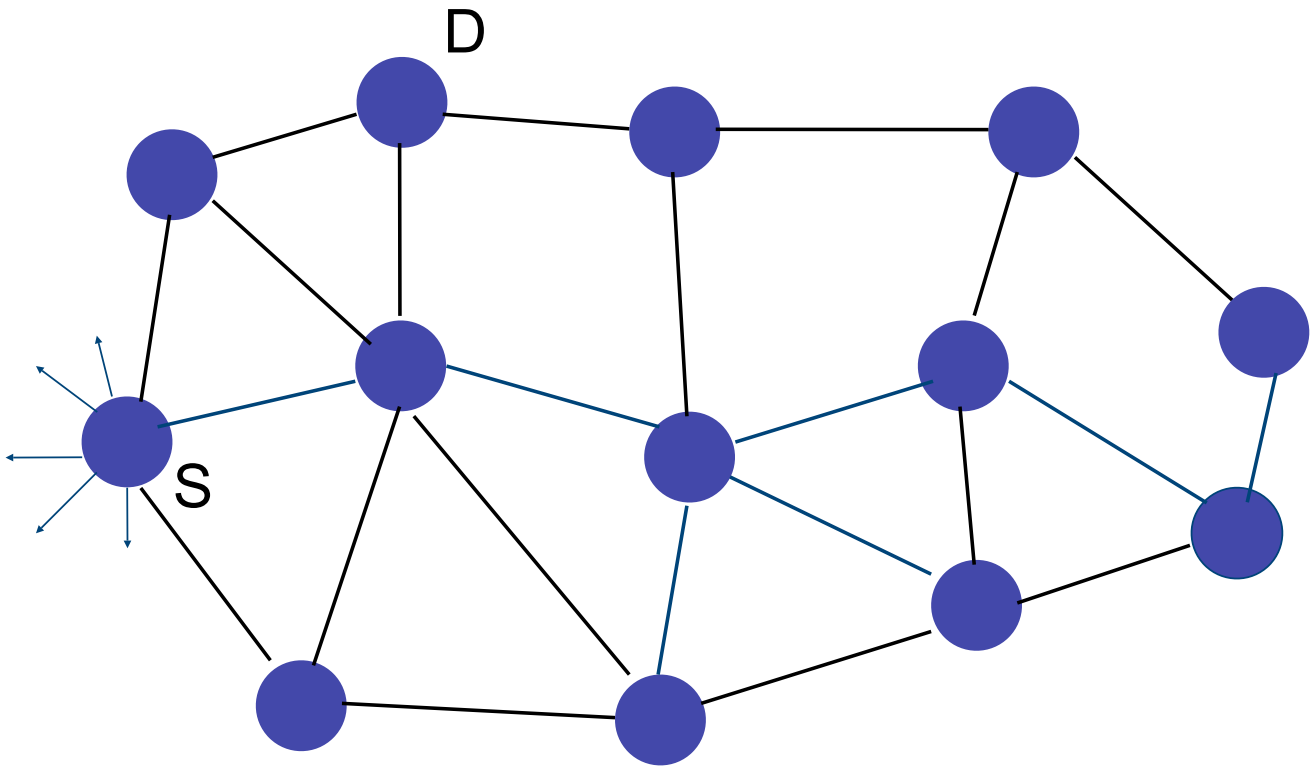


- An intermediate node P may receive more than one RREP for the same RREQ.
- P forwards the first RREP it receives and forwards a second RREP later only if :
  - The later RREP contains a greater sequence number for the destination, (RREP for later RREQ)
  - The hop-count to the destination is smaller in the later RREP
  - Otherwise, it does not forward the later RREPs. This reduces the number of RREPs propagating towards the source.

Expanding Ring Search

- For route discovery, a source node broadcasts a RREQ across the network. This may create a lot of messages in a large network.
- A source node uses an expanding ring search strategy. With a ring diameter K, a RREQ dies after its hop-count exceeds K.
- If a RREQ fails, the source node increases the value of K incrementally.

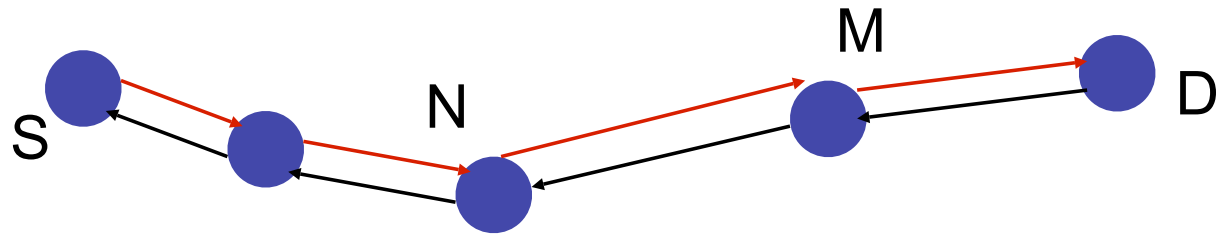
Example (Expanding Ring Search)



Routing Request Message:

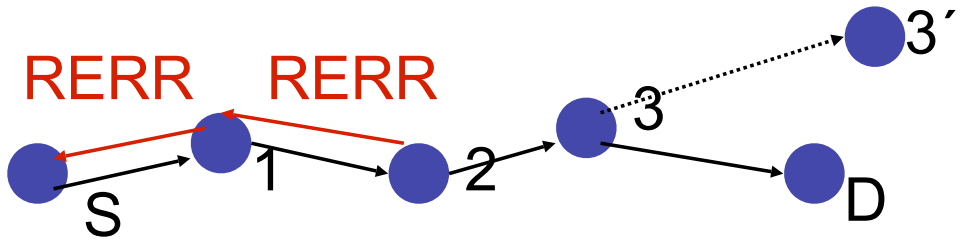
Source IP	Dest. IP	Source Seq. No.	Dest. Seq. No.	Broadcast Id	Hop Count	Time To Live
S	**D**	**5**	**4**	**3**	**0**	**1_{85}**

Route Maintenance



- Once a route has been established between two nodes S and D, it is maintained as long as S (source node) needs the route.
- If S moves during an active session, it can reinitiate route discovery to establish a new route to D.
- When D or an intermediate node moves, a route error (RERR) message is sent to S.

Route Error

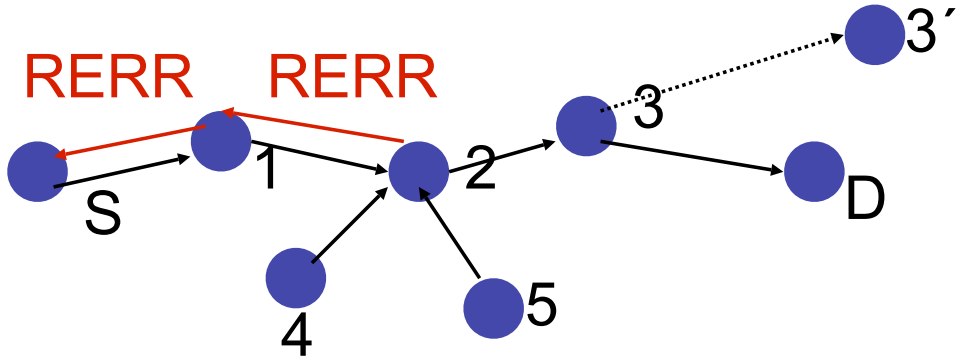


- If S moves during an active session, it can reinitiate route discovery to establish a new route to D.
- When D or an intermediate node moves, a route error (RERR) message is sent to S.

Example:

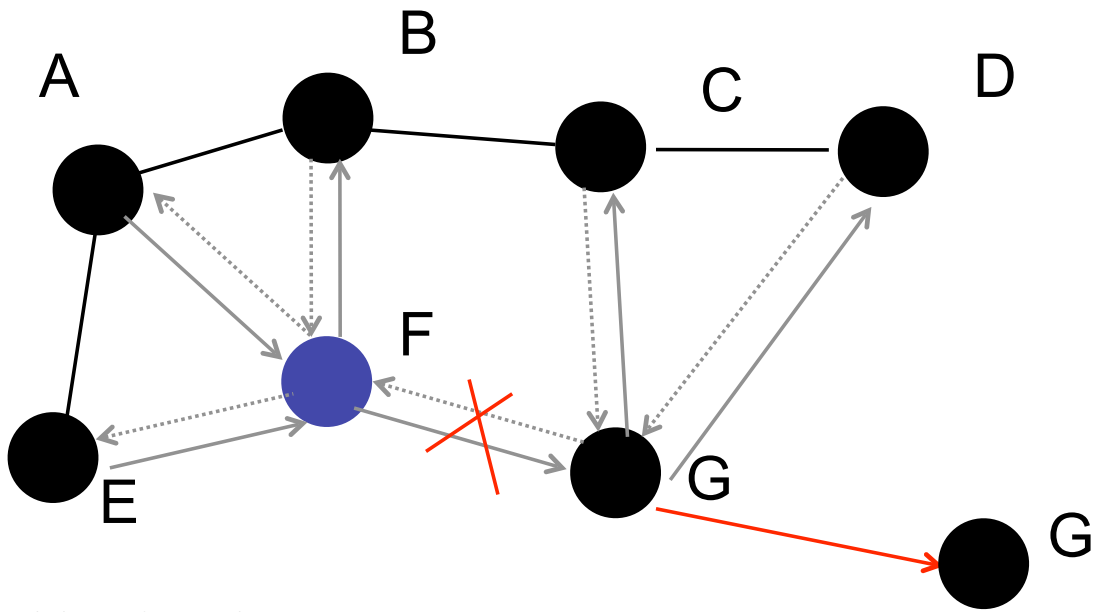
- The link from node 3 to D is broken as 3 has moved away to a position 3´.
- Node 2 sends a RERR message to 1 and 1 sends the message in turn to S.
- S initiates a route discovery if it still needs the route to D.

Updating Routing Tables



- Suppose neighbours 4 and 5 route through 2 to reach D. Node 2 broadcasts RERR to all such neighbours.
- Each neighbour marks its route table entry to D as invalid by setting the distance to infinity.
- Each neighbour in turn propagates the RERR message.

Example (Routing Error)



Routing Table of Node F:

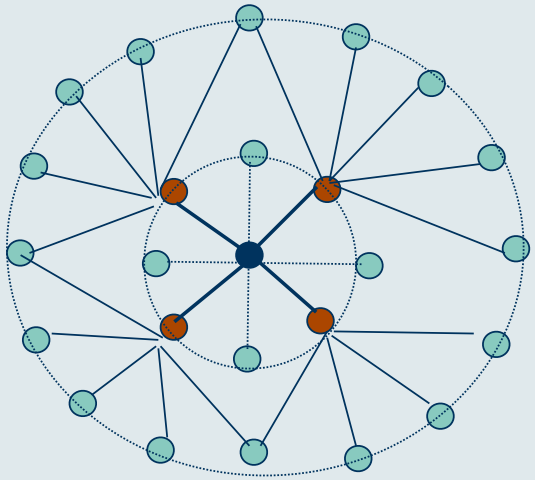
Dest. IP	Next Hop IP	Dest. SeqNo.	Lifetime	Precursors	Hop Count
B	B	2	10	E	1
C	G	4	6	E	2
D	G	4	8	A, E	2

Overview

• AODV does not retransmit data packets that are lost and hence does not guarantee packet delivery.
• However, the packet delivery percentage is close to 100 with relatively small number of nodes.
• The packet delivery percentage drops with increased mobility.
• The overhead packets in AODV are due to RREQ, RREP and RERR messages.
• AODV needs much less number of overhead packets compared to DSDV.
• The number of overhead packets increases with increased mobility, since this gives rise to frequent link breaks and route discovery.
• The route discovery latency in AODV is low compared to DSR and DSDV.

Overview

- **OLSR**
  - Developed by IETF
  - Table driven
  - Inherits Stability of
    Link-state protocol
  - Selective Flooding
  - Periodic Link State
    Information generated only by MPR
  - MPRs employed for optimization



Link State Routing (eg, OSPF)

- Each node periodically floods status of its links
- Each node re-broadcasts link state information received from its neighbour
- Each node keeps track of link state information received from other nodes
- Each node uses above information to determine next hope to each destination

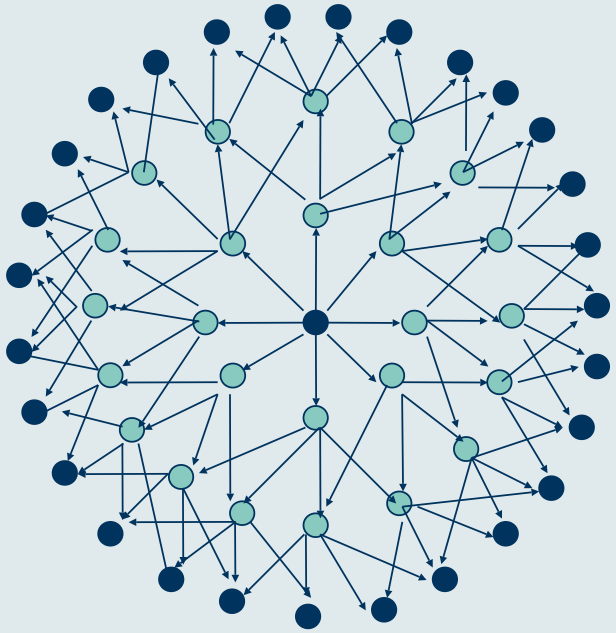
24 retransmissions to diffuse a message up to 3 hops

Retransmission node

OLSR Overview

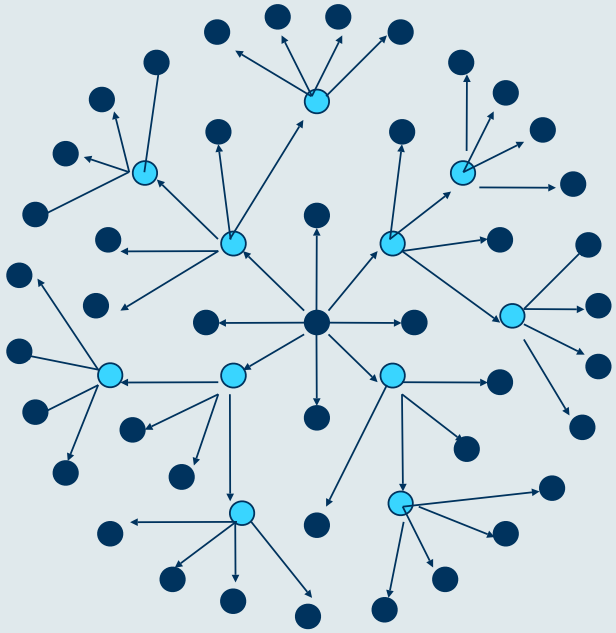
- **In LSR**
  - protocol a lot of control messages unnecessary duplicated
- **In OLSR**
  - **only** MPR retransmit control messages:
    - **Reduce size of control message;**
    - **Minimize flooding**
- Other advantages (the same as for LSR):
  - As **stable** as LSR protocol;
  - **Proactive** protocol(routes already known);
  - Does not depend upon any **central entity**;
  - **Tolerates** loss of control messages;
  - Supports nodes **mobility**.
  - Good for **dense network**

Optimized Link state routing (OLSR)



24 retransmissions to diffuse a message up to 3 hops

Retransmission node

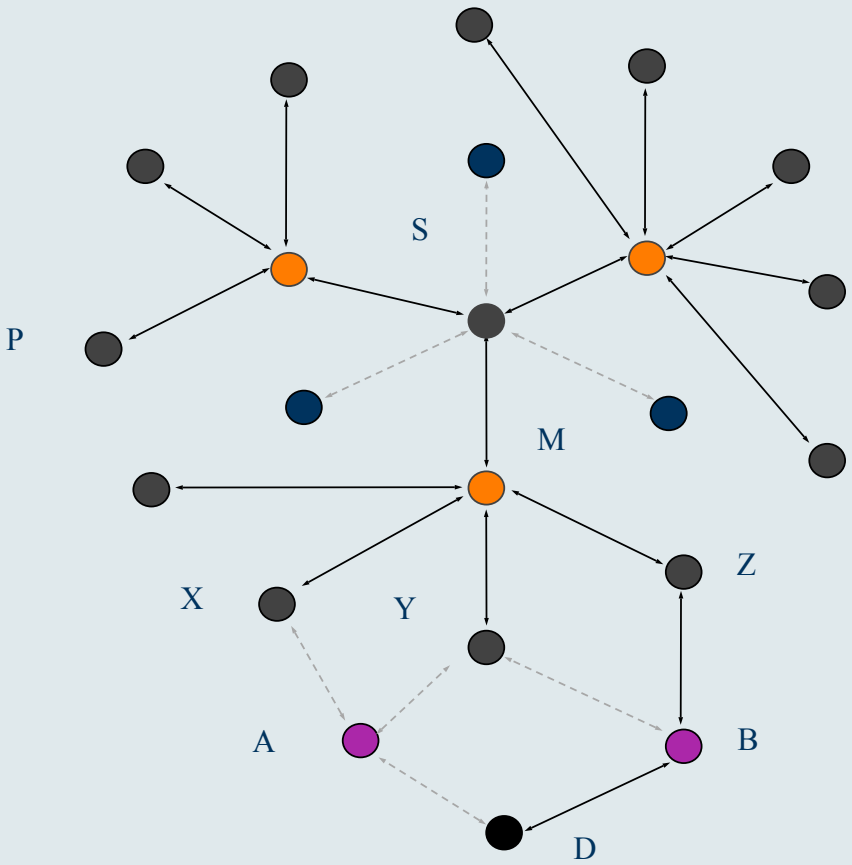


11 retransmission to diffuse a message up to 3 hops

Retransmission node

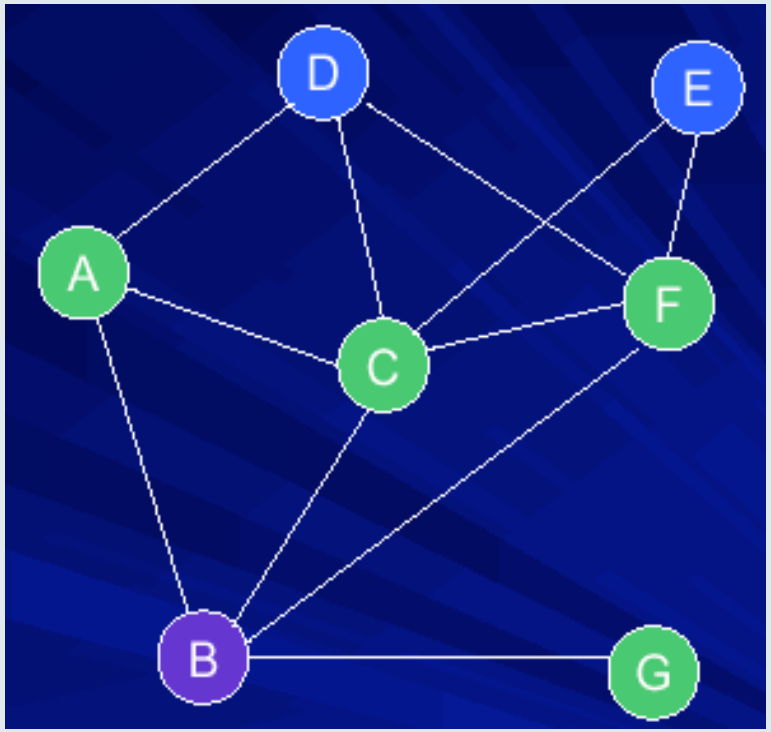
Description of OLSR

- MPR (Multipoint relays)
- MPR selector
- Symmetric 1-hop neighbours
- Symmetric strict 2-hop neighbours



Neighbor sensing

- Each node periodically broadcasts Hello message:
  - List of neighbors with bi-directional link
  - List of other known neighbors.
- Hello messages permit each node to learn topology up to 2 hops
- Based on Hello messages each node selects its set of MPR's



Example of neighbor table

One-hop neighbors

Neighbor's id	State of Link
B	Bidirectional
G	Unidirectional
C	MPR
…	…

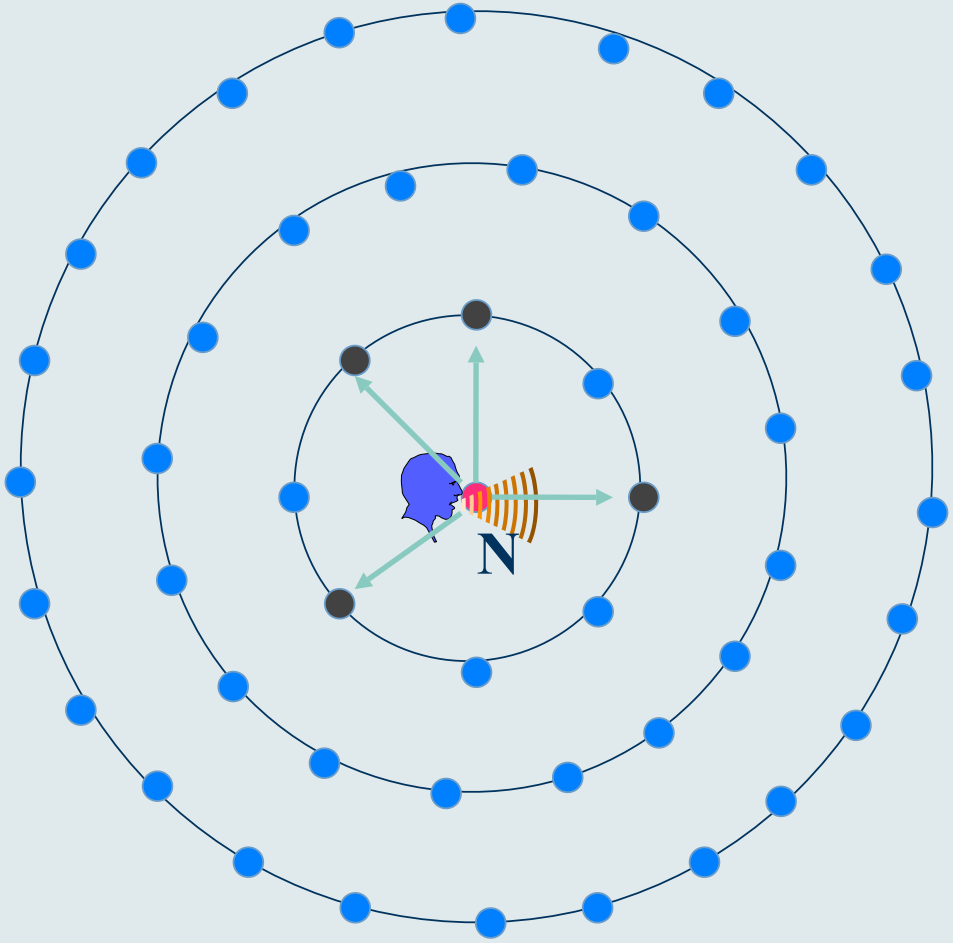
Two-hop neighbors

Neighbor's id	Access though
E	C
D	C
…	…

Also every entry in the table has a timestamp, after which the entry in not valid

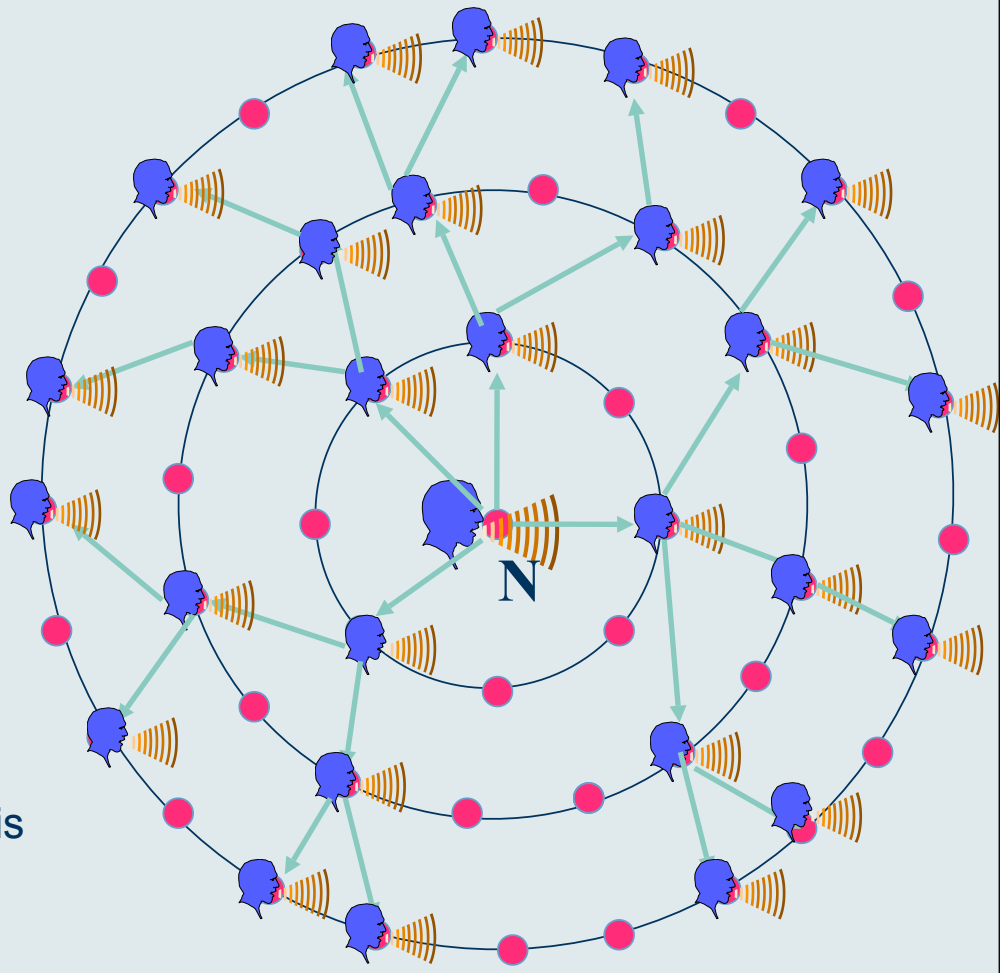
Multipoint Relays (MPR)

- **Reduce** re-transmission in the same region
- Each node select a set of ***MPR Selectors***
- MPR Selectors of node N - **MPR(N)**
  - one-hop neighbors of N



Multipoint Relays (MPR)

- **Reduce** re-transmission in the same region
- Each node select a set of ***MPR Selectors***
- MPR Selectors of node N - **MPR(N)**
  - one-hop neighbors of N
- MPR set of Node N
- Set of MPR's is able to transmit to all two-hop neighbors
- Link between node and it's MPR is **bidirectional.**



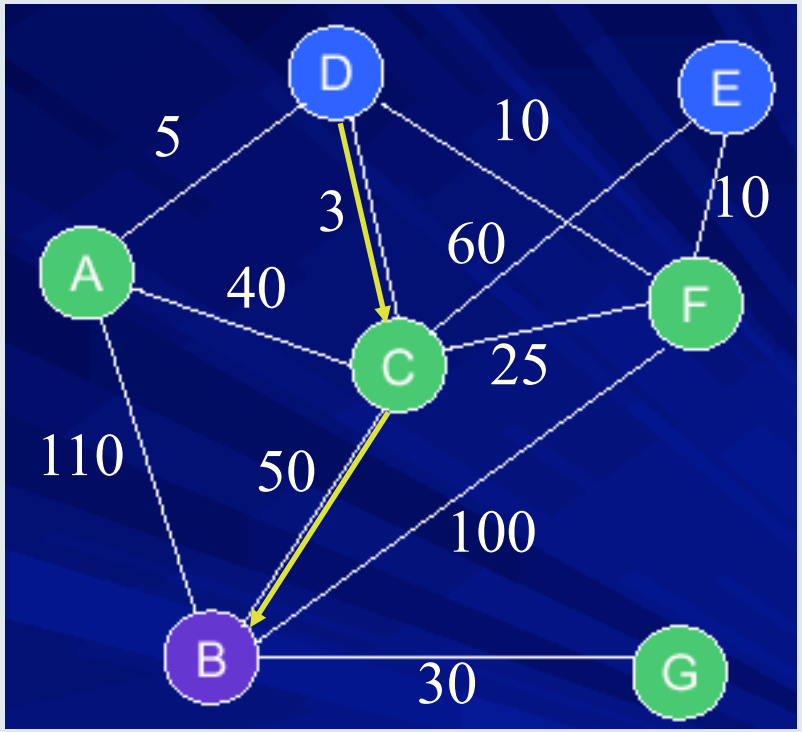
Multipoint Relays (MPR)

- Every node keeps a table of routes to all known destination through its MPR nodes
- Every node periodically broadcasts list of its MPR Selectors (instead of the whole list of neighbors).
- Upon receipt of MPR information each node recalculates and updates routes to each known destination

MRP selection in OLSR

Node	1 Hop Neighbors	2 Hop Neighbors	MPR(s)
B	A,C,F,G	D,E	C

- Available BW
- OLSR: node B will select C as its MPR So all the other nodes know that they can reach B via C
- D->B route is D-C-B, whose bottleneck BW is 3



MRP selection in OLSR

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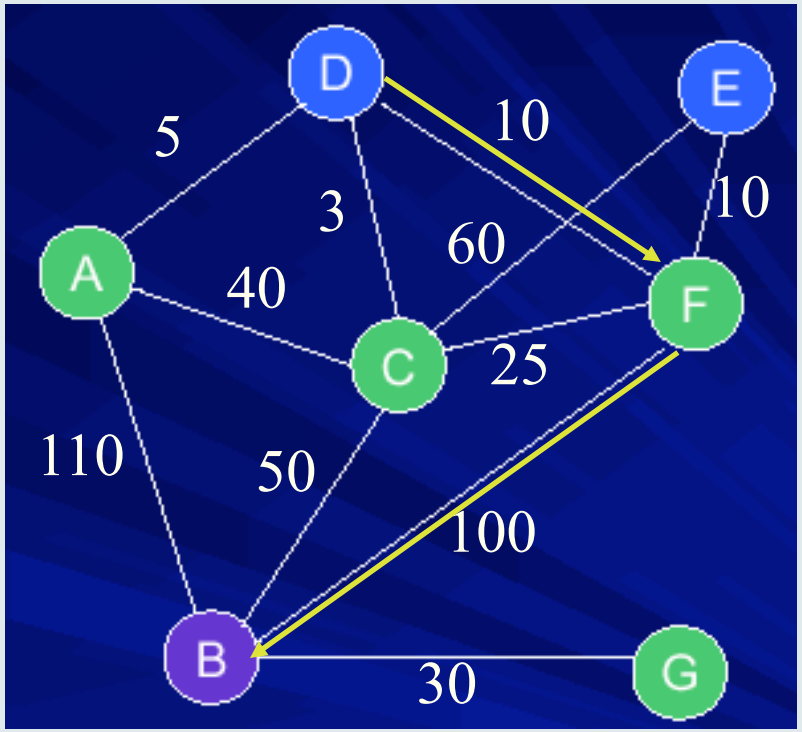
B	A,C,F,G	D,E	C

- Available BW
- OLSR: node B will select C as its MPR So all the other nodes know that they can reach B via C
- D->B route is D-C-B, whose bottleneck BW is 3
- Optimal route (i.e., path with maximum bottleneck bandwidth: D-F-B (bottleneck bandwidth of 10)



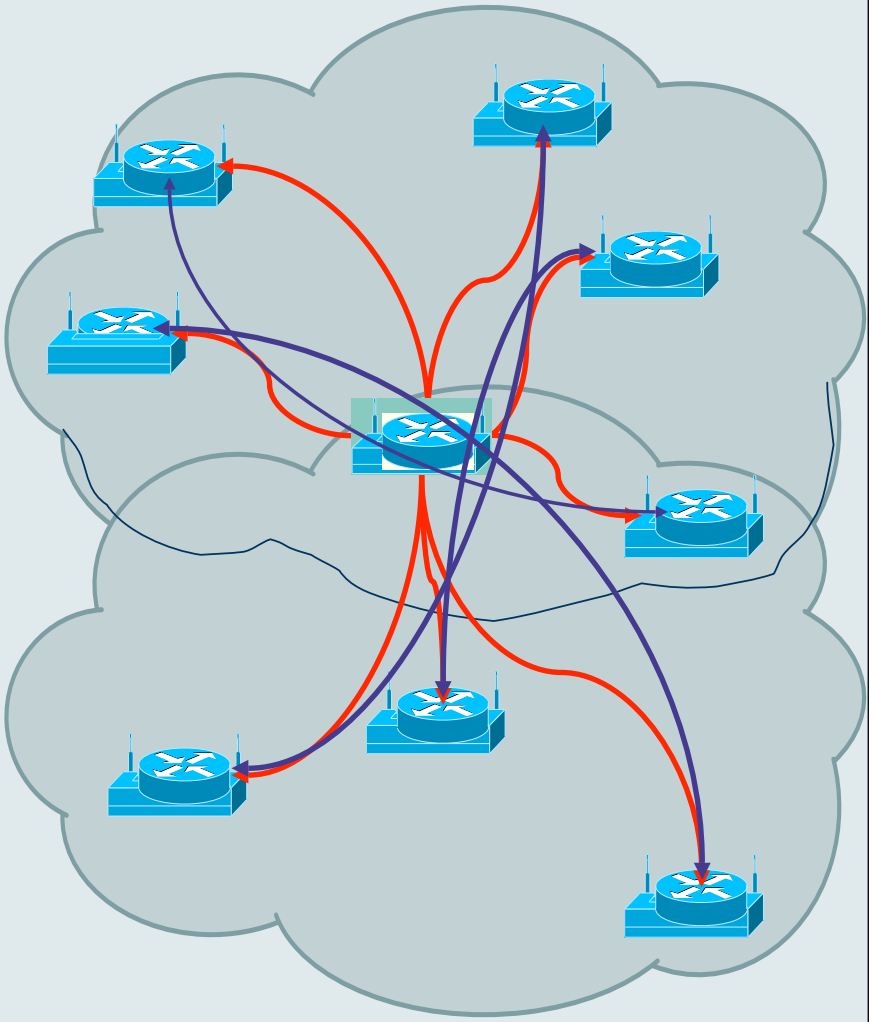
Multi-Point Relays/routers

Passes Topology Information

Acts as router between hosts

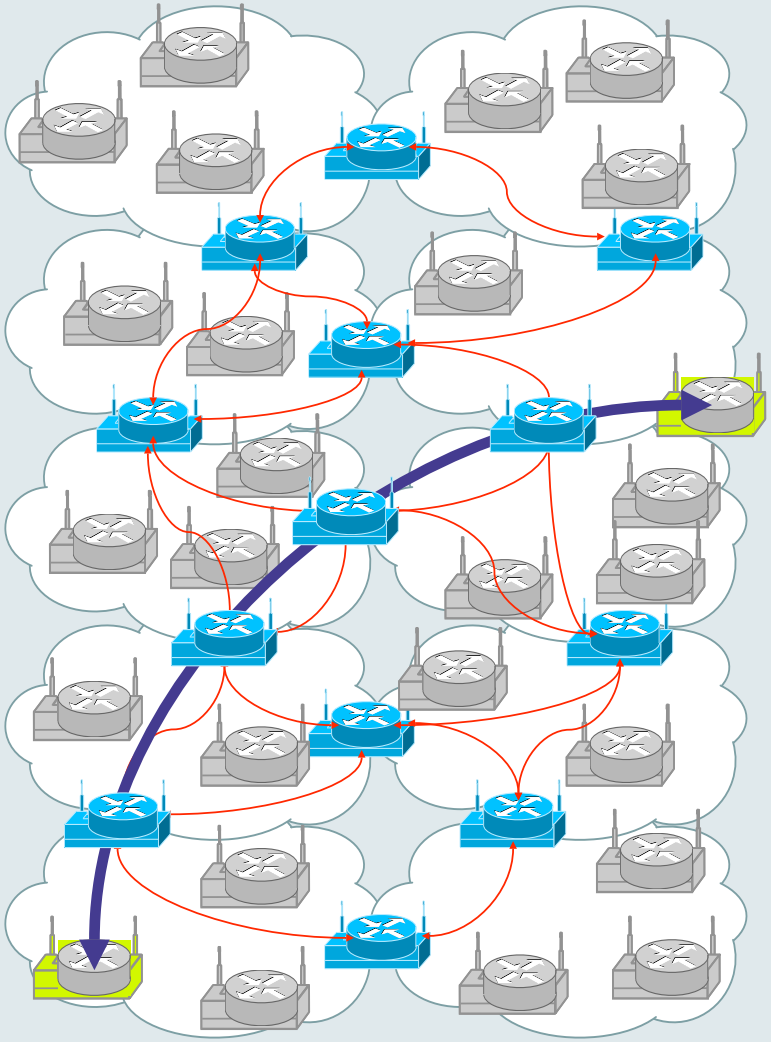
Minimizes information retransmission

Forms a routing backbone



Structure of an OLSR Network

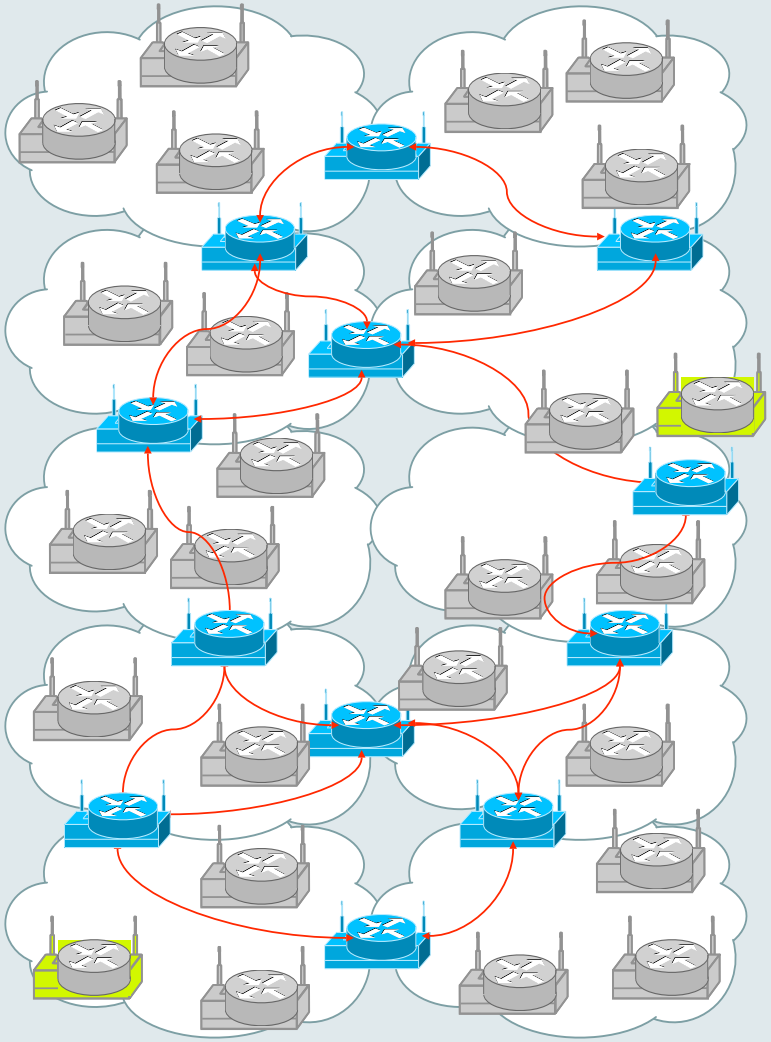
MPRs form **routing backbone**
Other nodes act as “hosts”



Structure of an OLSR Network

MPRs form **routing backbone**
Other nodes act as “hosts”

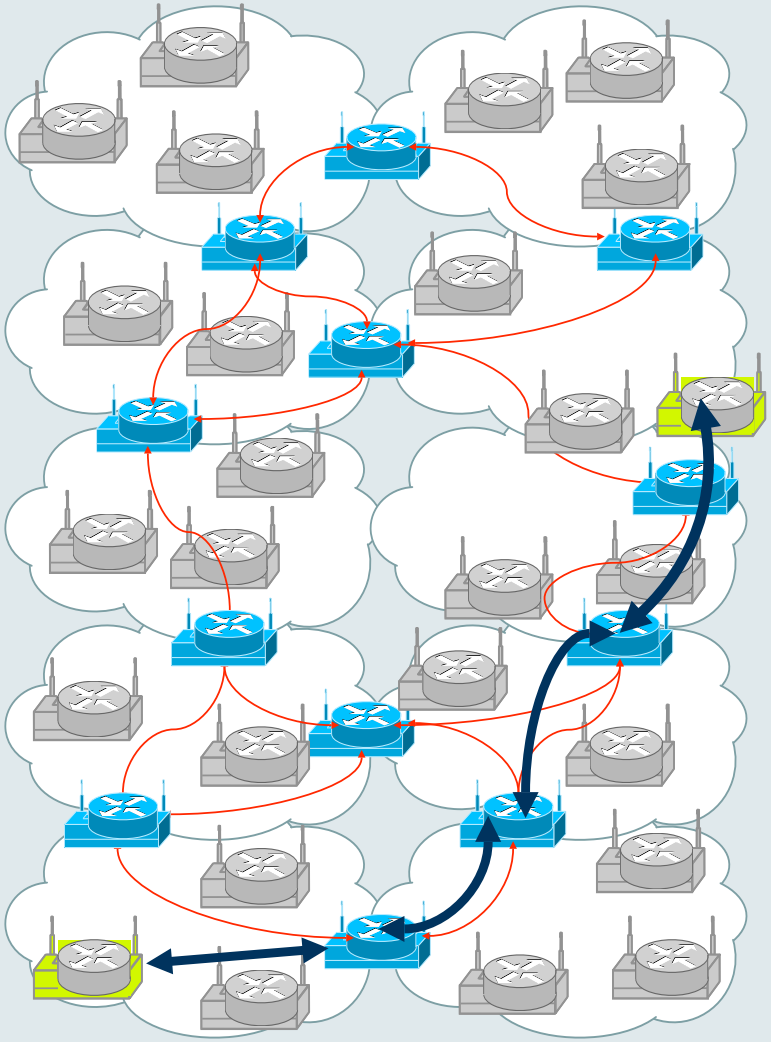
As devices **move**



Structure of an OLSR Network

MPRs form **routing backbone**
Other nodes act as “hosts”

As devices **move**
Topological relationships change
Routes change
Backbone shape and composition changes



MPR information declaration

- TC – Topology control message:
  - Sent **periodically**. Message might not be sent if there are no updates and sent earlier if there are updates
  - **Contains:**
    - MPR Selector Table
    - Sequence number
- Each node **maintains** a *Topology Table* based on TC messages
  - **Routing Tables** are calculated based on Topology tables

Topology Table

Destination address	Destination's MPR	MPR Selector sequence number	Holding time

MPR Selector in the received TC message

Last-hop node to the destination.

Originator of TC message

Topology Table (cont)

- Upon receipt of TC message:
  - If there exist some entry to the same destination with **higher** Sequence Number, the TC message is ignored
  - If there exist some entry to the same destination with **lower** Sequence Number, the topology entry is removed and the new one is recorded
  - If the entry is the **same** as in TC message, the holding time of this entry is refreshed
  - If there are **no** corresponding entry – the new entry is recorded

Routing Table

- **Each node** maintains a routing table to all known destinations in the network
- Routing table is **calculated** from Topological Table, taking the connected pairs
- Routing table:
  - **Destination address**
  - **Next Hop address**
  - **Distance**
- Routing Table is **recalculated** after every change in neighborhood table or in topological table

802.11s

- Extension de 802.11 para definir soporte para redes Ad-hoc en 802.11
  - Aun esta en draft pero podria aprobarse muy pronto
- Dispositivos Mesh Points (MPs)
- Enrutamiento obligatorio por defecto HMMP (Hybrid Wireless Mesh Protocol)
  - Basado en AODV y enrutamiento basado en arboles
- Enrutamiento alternativo OLSR
- Los MPs pueden comunicarse entre si
- Los MPs pueden ser access points que dan acceso a redes 802.11 de tipo infraestructura
- Los MPs pueden ser gateways a la red cableada

- El proyecto OLPC dice soportar 802.11s

Movilidad...

Ad-hoc

OLSR Concepts (1)

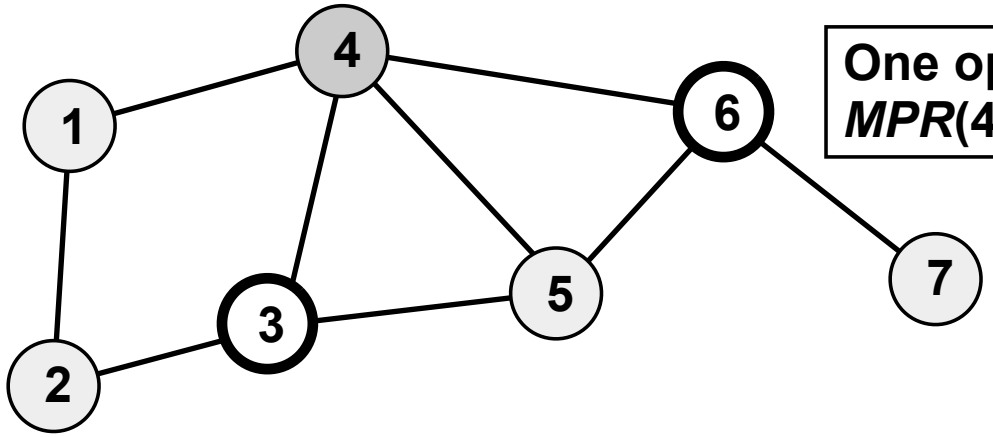
- Proactive (table-driven) routing protocol
  - A route is available immediately when needed
- Based on the link-state algorithm
  - Traditionally, all nodes flood neighbor information in a link-state protocol, but not in OLSR
- Nodes advertise information only about links with neighbors who are in its *multipoint relay selector set*
  - Reduces size of control packets
- Reduces flooding by using only *multipoint relay* nodes to send information in the network
  - Reduces number of control packets by reducing duplicate transmissions

OLSR Concepts (2)

- Does not require reliable transfer, since updates are sent periodically
- Does not need in-order delivery, since sequence numbers are used to prevent out-of-date information from being misinterpreted
- Uses hop-by-hop routing
  - Routes are based on dynamic table entries maintained at intermediate nodes

Multipoint Relays

- Each node *N* in the network selects a set of neighbor nodes as multipoint relays, *MPR*(*N*), that retransmit control packets from *N*
  - Neighbors not in *MPR*(*N*) process control packets from *N*, but they do not forward the packets
- *MPR*(*N*) is selected such that all two-hop neighbors of *N* are covered by (one-hop neighbors) of *MPR*(*N*)

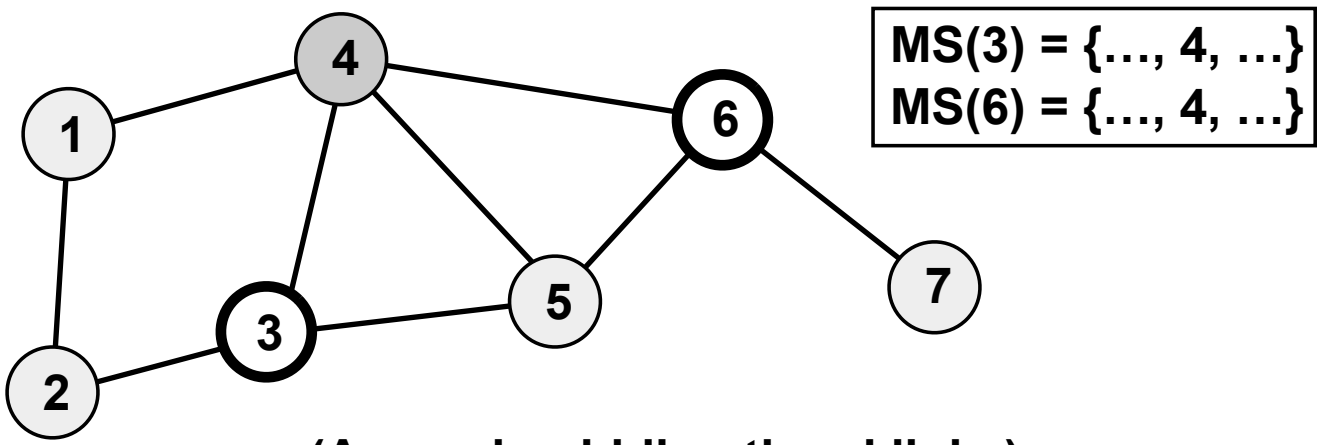


One optimal set for Node 4:
MPR(4) = { 3, 6 }

Is there another optimal *MPR*(4)?

Multipoint Relay Selector Set

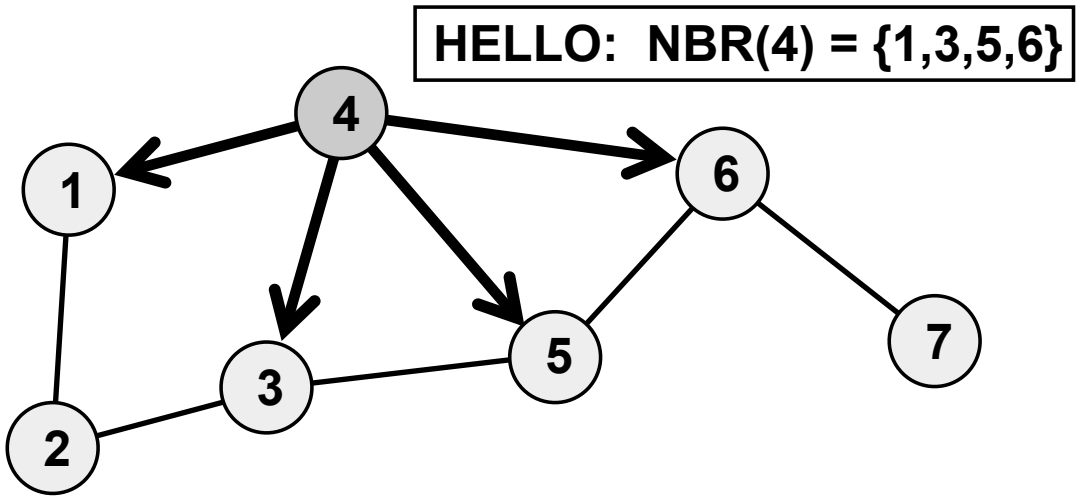
- The multipoint relay selector set for Node *N*, *MS*(*N*), is the set of nodes that choose Node *N* in their multipoint relay set
  - Only links *N-M*, for all *M* such that $N \in MS(M)$ will be advertised in control messages



(Assuming bidirectional links)

HELLO Messages (1)

- Each node uses HELLO messages to determine its MPR set
- All nodes periodically broadcast HELLO messages to their one-hop neighbors (bidirectional links)
- HELLO messages are not forwarded

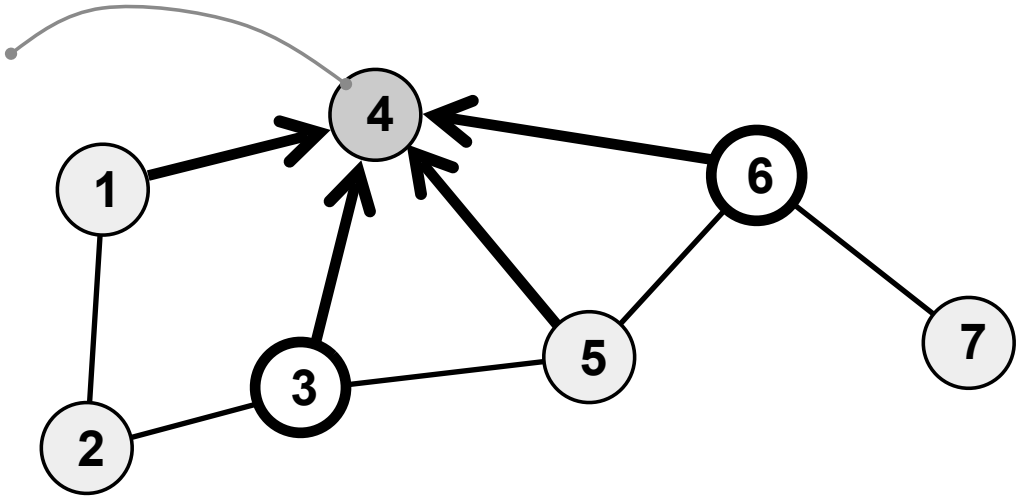


HELLO Messages (2)

- Using the neighbor list in received HELLO messages, nodes can determine their two-hop neighborhood and an optimal (or near-optimal) MPR set
- A sequence number is associated with this MPR set
  - Sequence number is incremented each time a new set is calculated

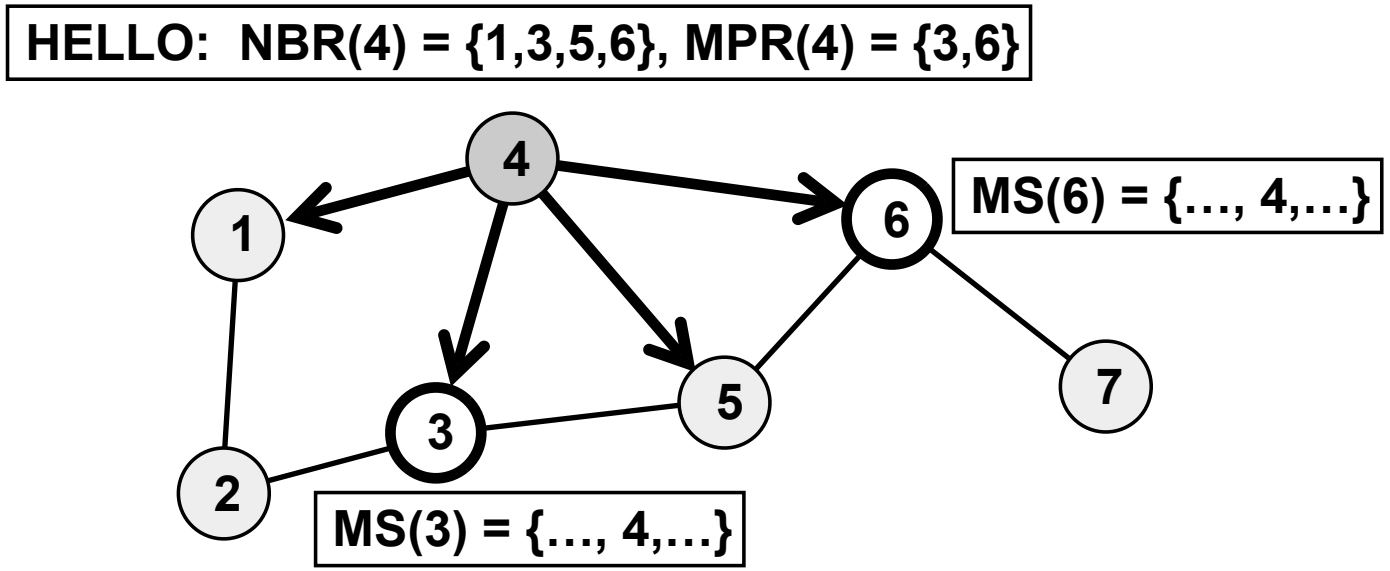
At Node 4:
NBR(1) = {2}
NBR(3) = {2,5}
NBR(5) = {3,6}
NBR(6) = {5,7}

MPR(4) = {3,6}



HELLO Messages (3)

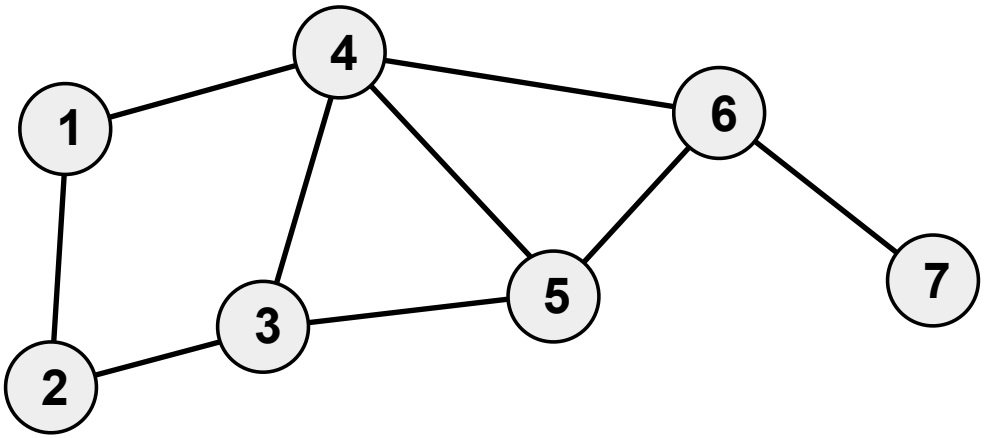
- Subsequent HELLO messages also indicate neighbors that are in the node's MPR set
- MPR set is recalculated when a change in the one-hop or two-hop neighborhood is detected



TC Messages

- Nodes send topology information in Topology Control (TC) messages
  - List of advertised neighbors (link information)
  - Sequence number (to prevent use of stale information)
- A node generates TC messages only for those neighbors in its MS set
  - Only MPR nodes generate TC messages
  - Not all links are advertised
- A nodes processes all received TC messages, but only forwards TC messages if the sender is in its MS set
  - Only MPR nodes propagate TC messages

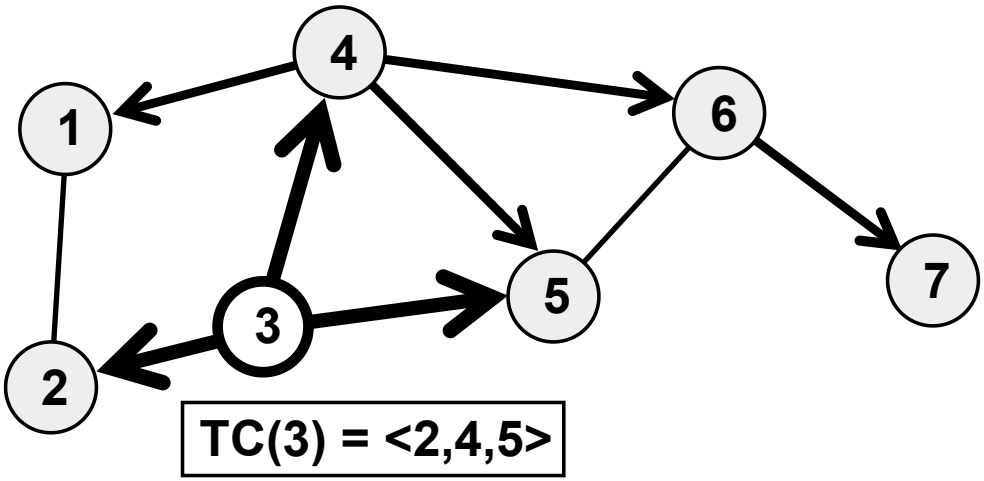
OLSR Example (1)



MPR(1) = { 4 }
MPR(2) = { 3 }
MPR(3) = { 4 }
MPR(4) = { 3, 6 }
MPR(5) = { 3, 4, 6 }
MPR(6) = { 4 }
MPR(7) = { 6 }

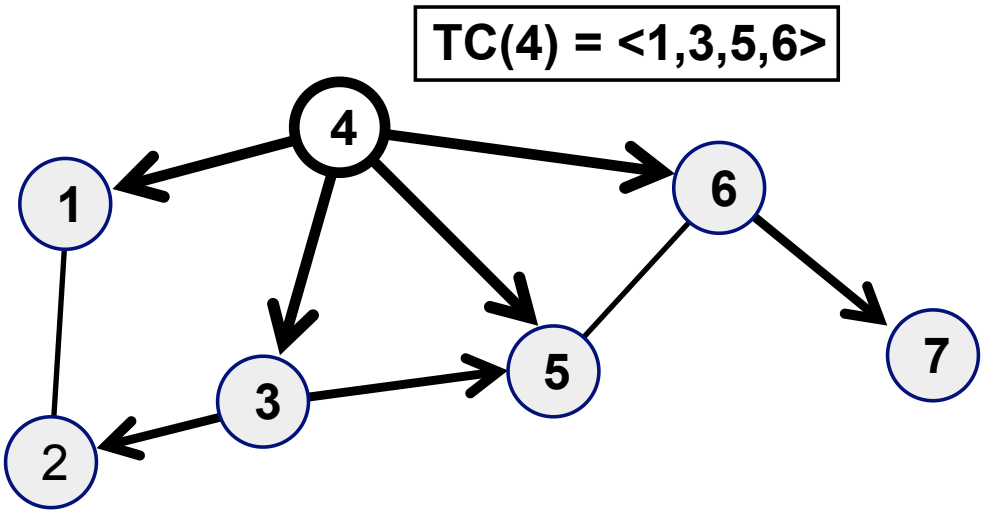
MS(1) = { }
MS(2) = { }
MS(3) = { 2, 4, 5 }
MS(4) = { 1, 3, 5, 6 }
MS(5) = { }
MS(6) = { 4, 5, 7 }
MS(7) = { }

OLSR Example (2)



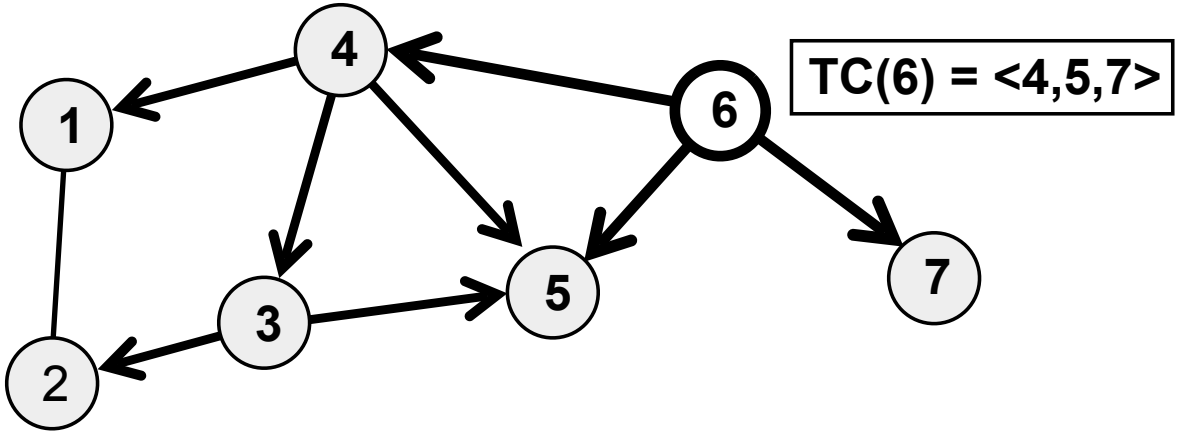
- Node 3 generates a TC message advertising nodes in MS(3) = {2, 4, 5}
- Node 4 forwards Node 3's TC message since Node 3 $\in$ MS(4) = {1, 3, 5, 6}
- Node 6 forwards TC(3) since Node 4 $\in$ MS(6)

OLSR Example (3)



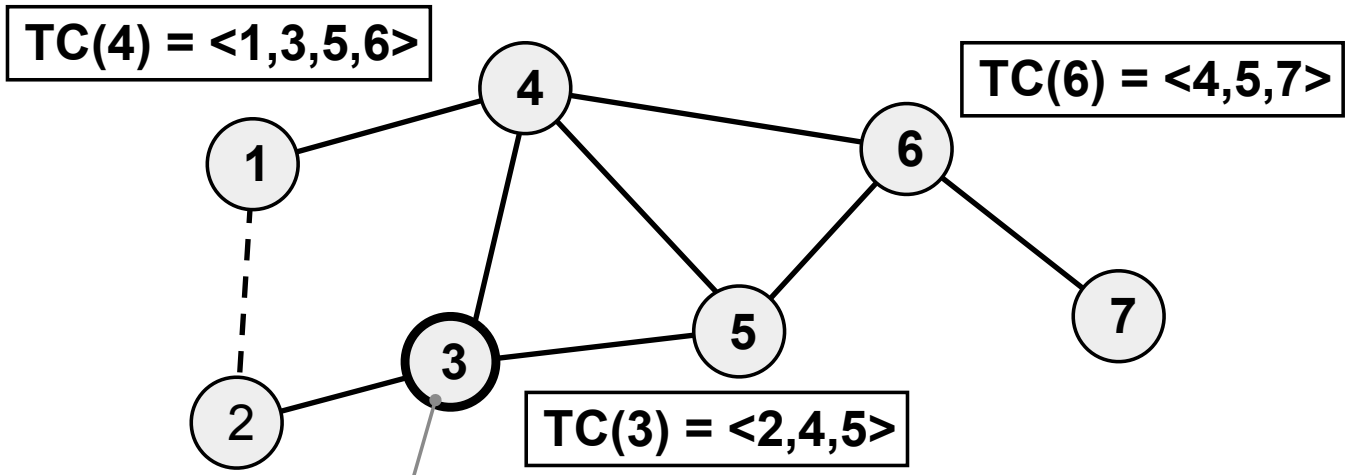
- Node 4 generates a TC message advertising nodes in MS(4) = {1, 3, 5, 6}
- Nodes 3 and 6 forward TC(4) since Node 4 $\in$ MS(3) and Node 4 $\in$ MS(6)

OLSR Example (4)



- Node 6 generates a TC message advertising nodes in MS(6) = {4, 5, 7}
- Node 4 forwards TC(6) from Node 6 and Node 3 forwards TC(6) from Node 4
- After Nodes 3, 4, and 6 have generated TC messages, all nodes have link-state information to route to any node

OLSR Example (5)



Dest	*Next*	*Hops*
1	4	2
2	2	1
4	4	1
5	5	1
6	4 (5)	2
7	4 (5)	3

- Given TC information, each node forms a topology table
- A routing table is calculated from the topology table
- Note that Link 1-2 is not visible except to Nodes 2 and 3

802.11s

- Extension de 802.11 para definir soporte para redes Ad-hoc en 802.11
  - Aun esta en draft pero podria aprobarse muy pronto
- Dispositivos Mesh Points (MPs)
- Enrutamiento obligatorio por defecto HMMP (Hybrid Wireless Mesh Protocol)
  - Basado en AODV y enrutamiento basado en arboles
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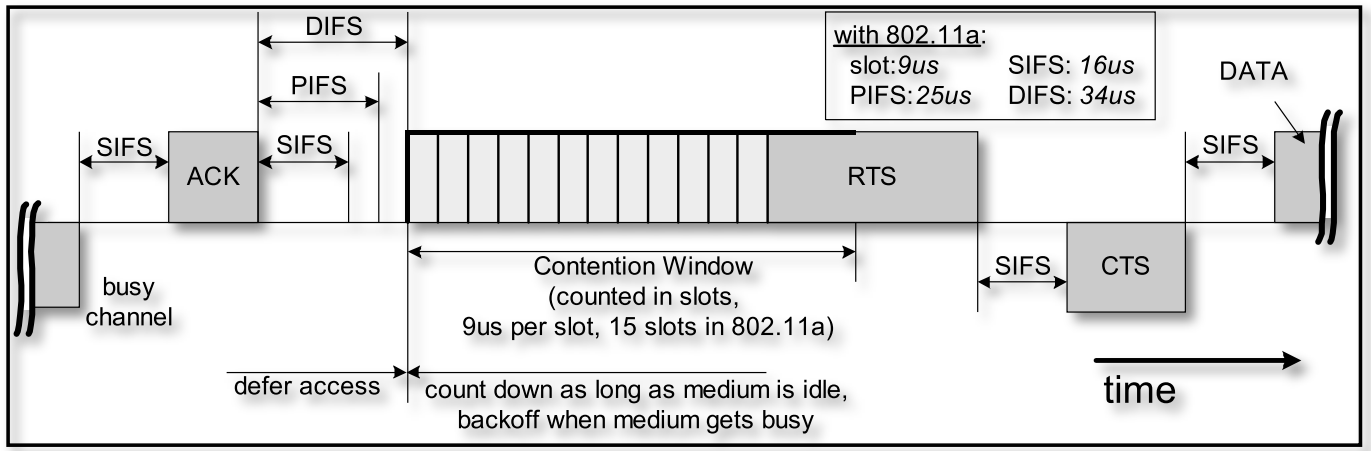
- El proyecto OLPC dice soportar 802.11s

802.11e

802.11 sin QoS

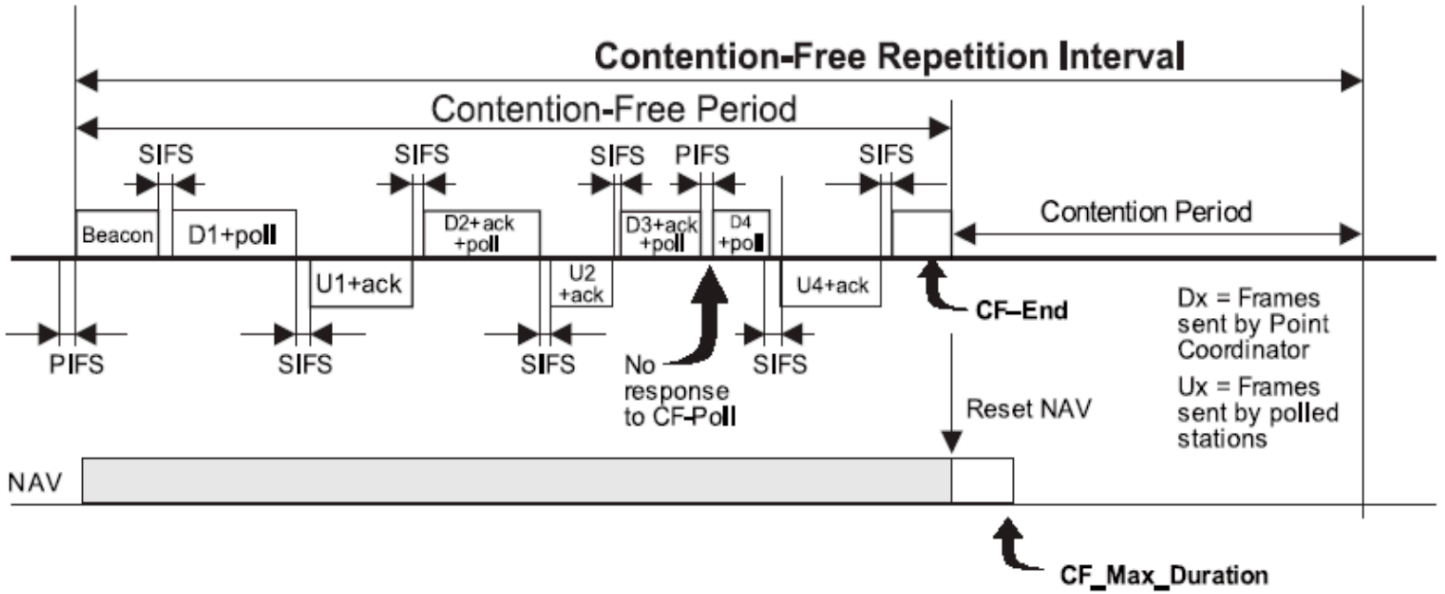
- DCF (Distributed Coordination Function)



SIFS : small inter frame space
DIFS : DCF inter frame space
PIFS : PCF inter frame space

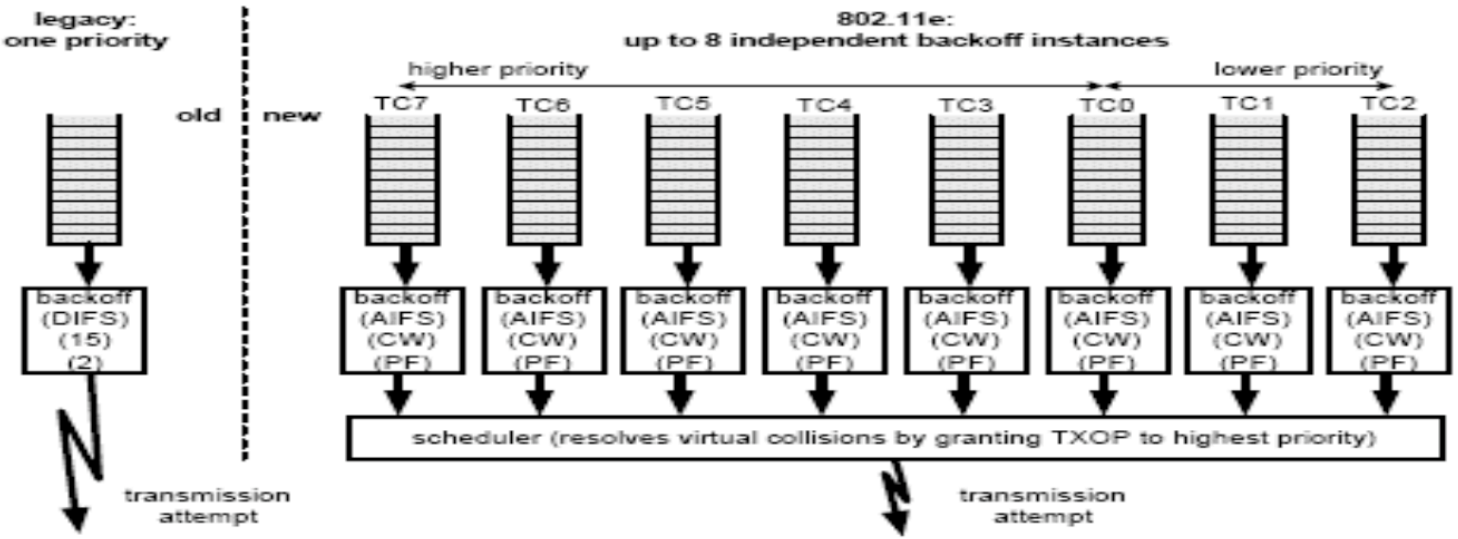
802.11 sin QoS

- PCF (Point Coordination Function)



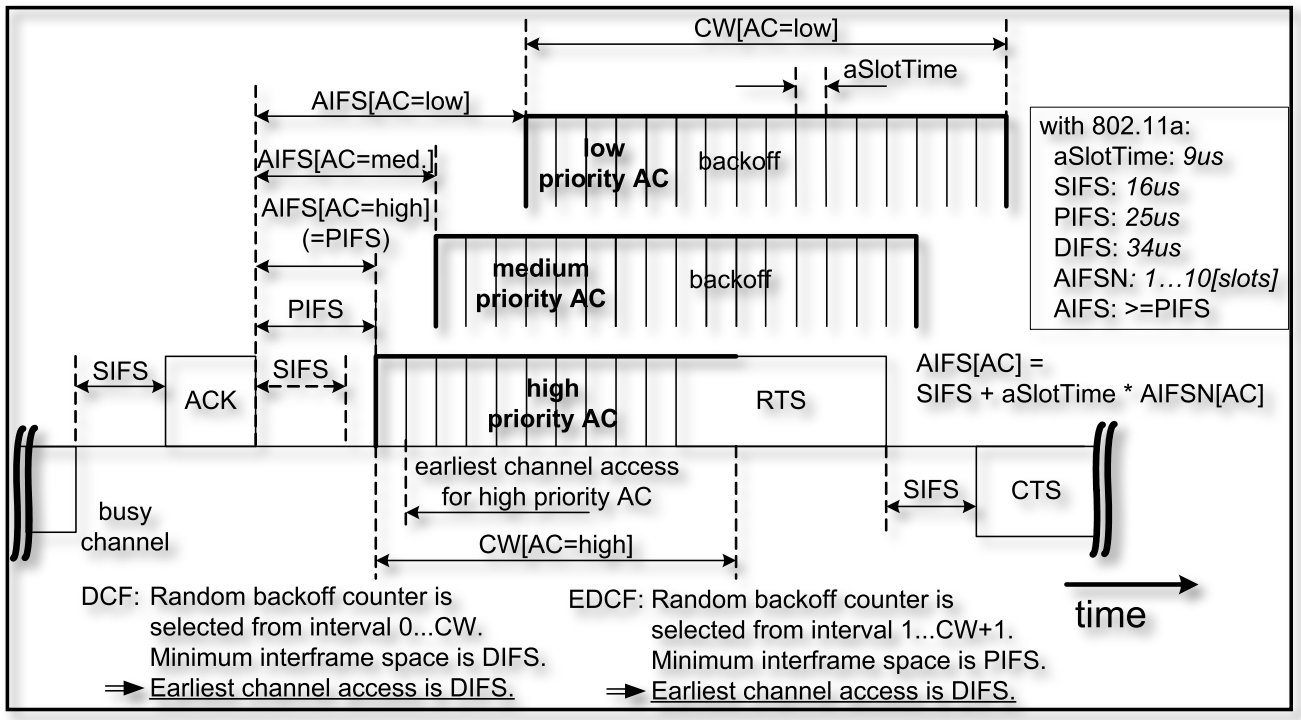
802.11e

- Clases de acceso AC para diferentes traffic categories TC



802.11e Medium Access: HCF

- Contention-based medium access: EDCF (Enhanced DCF)
- Different EDCF parameters per Access Category (AC)
  - DIFS→AIFS[AC]
  - CWmin→CWmin[AC]
  - CWmax→CWmax[AC]
  - (PF=2→PF[AC]*)



EDCF Summary

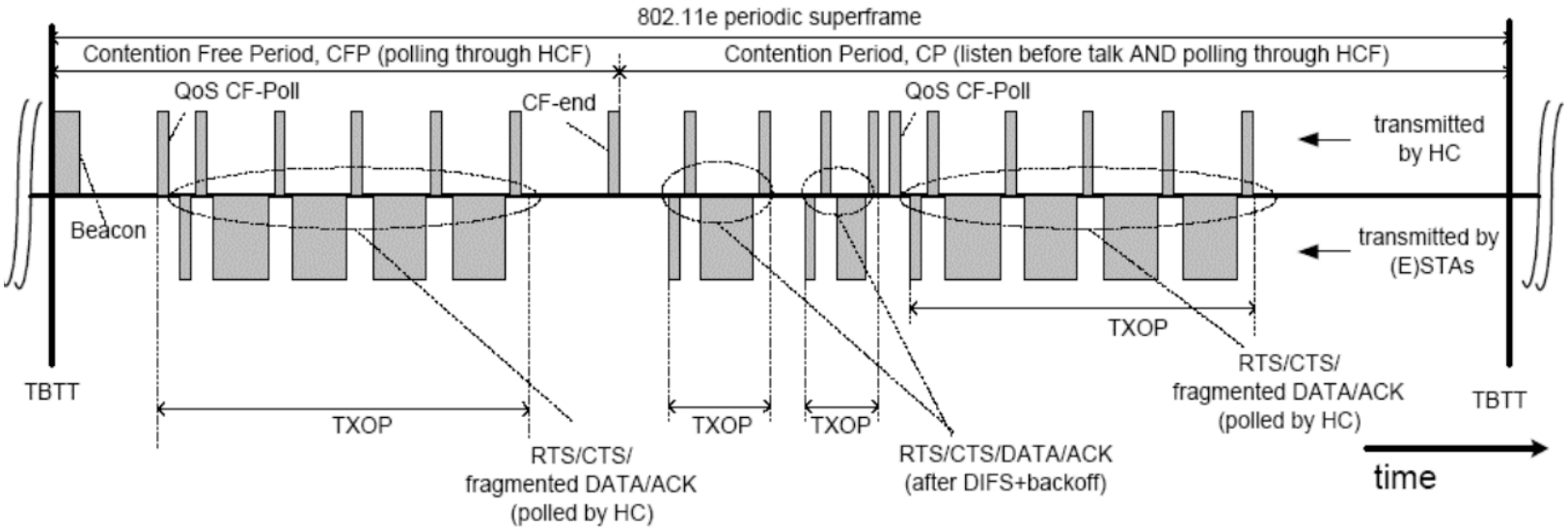
- EDCF MAC protocol is distributed (as DCF, simple)
- Multiple queues per station (queue = backoff entity)

- EDCF supports QoS, but cannot guarantee as resulting share depends on activity of other backoff entities

QoS Support in legacy 802.11? → no!
QoS Support in 802.11e EDCF? → yes, but no guarantee!

HCF Controlled Medium Access

- EDCF cannot guarantee QoS, because of distributed MAC
- For guarantee, controlled medium access allows access right after PIFS, without backoff
- Similar to polling in legacy 802.11 (PCF)



- El HC puede dar el canal a estaciones que tienen reservado BW
- Incluso fuera del periodo de CFP

WiFI Multimedia (WMM)

- Perfil de 802.11e basado en EDCF unicamente
- Priorización de tráfico basado en cuatro clases de acceso
  - WMM Voice
  - WMM Video
  - WMM Best Effort
  - WMM Background
- Implementaciones comerciales