



Chapter 11: Integrating MANETs, WLANs and Cellular Networks

Table of Contents

- **Introduction**
- **Ingredients of a Heterogeneous Architecture**
 - **Mobile User Stations**
 - **Base Station and Access Point**
 - **Core IP Network (CN)**
 - **Possible Communication Scenarios**
 - **Design Factors**
- **Protocol Stack**
 - **The Physical Layer**
 - **The Data Link Layer**
 - **The Network Layer**
 - **Transport Layer**
 - **Application Layer**
 - **Mobility and Connection Management**
- **Comparison of the Integrated Architectures**
- **Conclusions and Future Directions**



Introduction

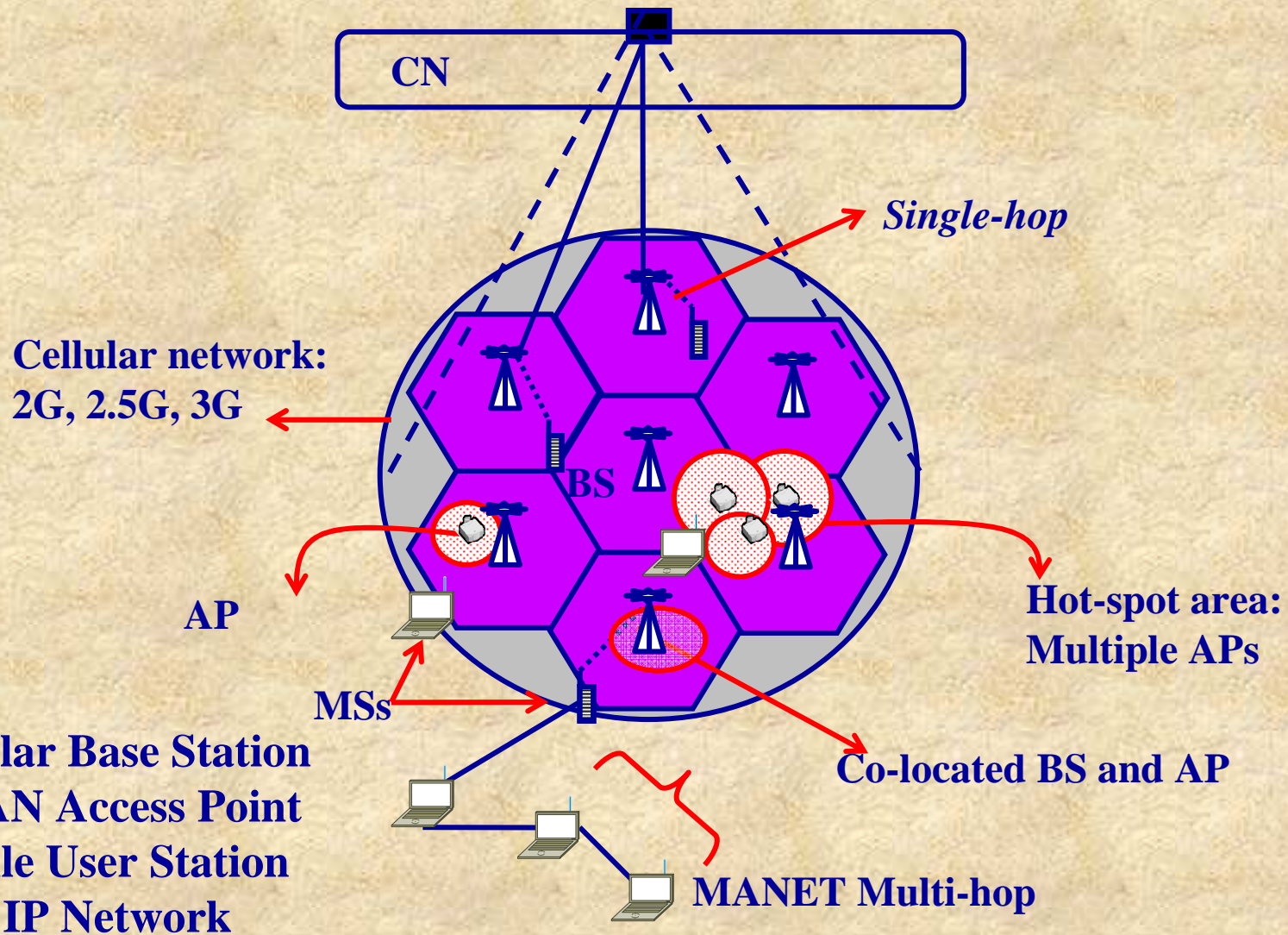
- **Advances in wireless communications have expanded to new integrated data applications**
- **Wireless LANs have become popular for allowing high data rates at relatively low cost**
- **WLAN Access Points (AP) provide hot spot connectivity in places, such as:**
 - **Airports**
 - **Hotels**
 - **Shopping malls**
 - **Schools**
 - **University campuses**
 - **Homes**
- **Future advances in software defined radio will make multi-interface, multi-mode and multi-band communication devices a commonplace**
- **Such an integrated heterogeneous environment enables a user to access a cellular network, a WLAN, or a WWAN, depending on the application needs and the types of radio access networks (RANs) available**
- **First step is to integrate WLANs, Wireless WANs, Wireless MANs by users accessing through a fixed Base Station (BS) or AP**
 - **WLANs (e.g., IEEE 802.11a/b/g/n and HiperLAN/2),**
 - **Wireless MANs (e.g., IEEE 802.16 and Wireless RANs (e.g., IEEE 802.22)**
- **The second step is to extend this to multi-hop MANETs**



Introduction

- **Global heterogeneous architectures need to provide seamless integration of one-hop and multi-hop wireless, with countless possibilities**
- **Users would have profiles such as price, data rate, battery life, service grade, and mobility pattern**
- **If a node is not directly within the coverage area of a RAN, then we have to explore the possibility of reaching a RAN through multi-hopping**
- **Internetworking of cellular systems with WLAN hot spots has also been investigated by standardization bodies, such as 3GPP and 3GPP2**
- **The basic integration aspects are the network selection, AAA (Authentication, Authorization and Accounting) and routing through the fixed infrastructure to the APs and the 3G network**
- **The 3GPP2 group developing 3GPP and 3GPP2 does not address the issues related to multi-hop communications**
- **The integration with the MANET paradigm is much more challenging and complex**

Heterogeneous Architecture





Single Mode V/s Dual Modes

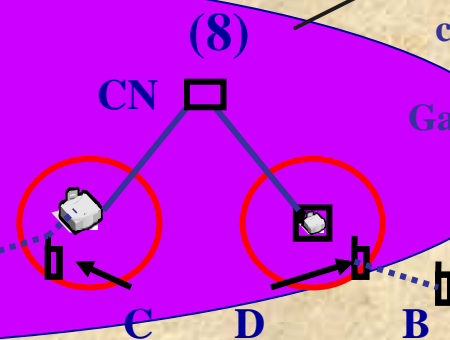
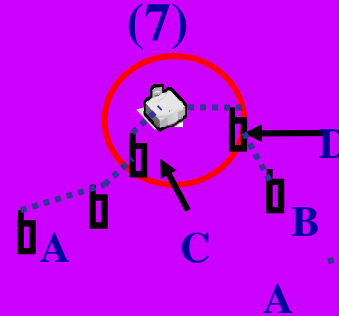
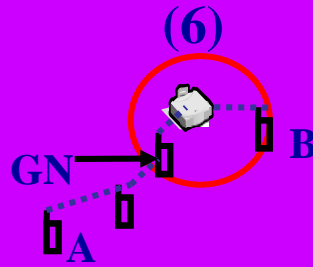
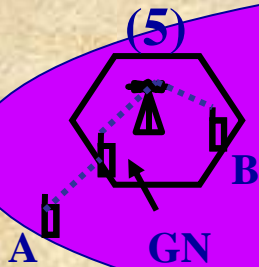
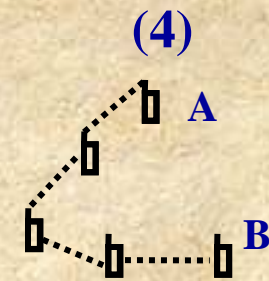
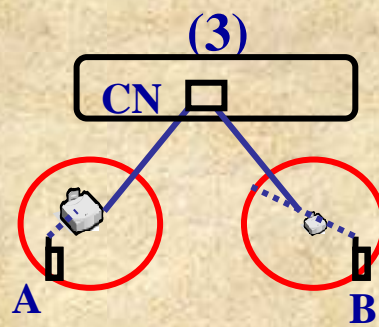
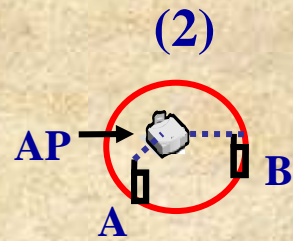
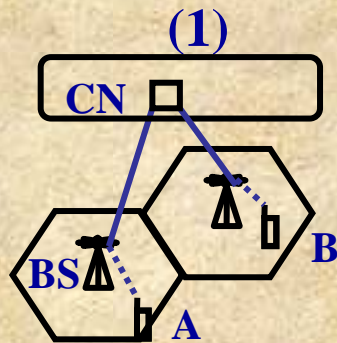
- **Basic mobile stations types:**
 - **Single-mode cellular MH**
 - **Single-mode WLAN MH or**
 - **Dual-mode MH**
- **A single-mode cellular MH connects to a cellular network through a BS**
- **A single-mode WLAN can communicate through an AP or can connect to other WLAN equipped terminals in the ad hoc mode forming a MANET**
- **A dual-mode MH can operate in both the cellular based mode (communicating directly to a BS or AP) or in the MANET mode using the WLAN interface**
 - **In the UCAN architecture, each MH uses two air interfaces: a HDR (High Data Rate) interface for communicating with BS and an IEEE 802.11 based interfaces for peer-to-peer communication.**
 - **More and more MHs will be equipped with multiple interfaces based on different wireless medium accessing technologies so that higher data speed rate could be supported**



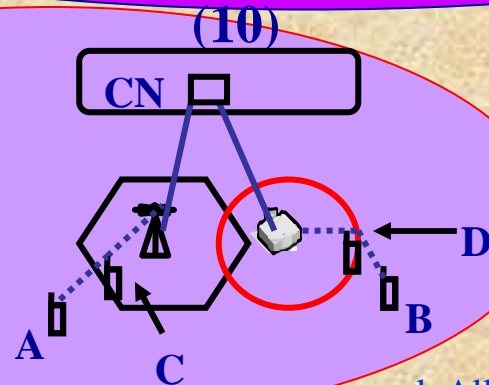
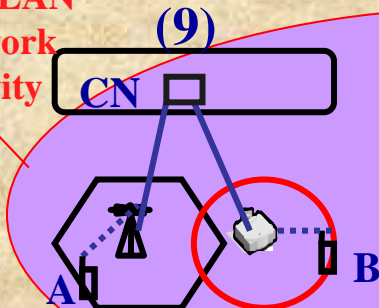
Base Station and Access Point

- **BSs and APs can provide several services to MHs including:**
 - **Accessibility to the Internet**
 - **Interoperability of existing networks and future networks**
 - **Support of handoff between different wireless networks**
 - **Resources control**
 - **Routing discovery**
 - **Security management**
- **Both BS and AP should have the capability of interoperability with each other**
- **The APs and BSs also have the responsibility to manage and control radio resources to the MHs**
- **Frequency allocation becomes more complicated, as different wireless technologies may operate in the same frequency band**

10 Alternatives between dual modes A and B



Require Cellular/WLAN fixed network connectivity



Out of coverage multi-hop connectivity through Gateway Nodes

- BS : Cellular Base Station
- AP : WLAN Access Point
- CN : Core IP Network
- GN : Gateway Node
- Hexagon represents a BS coverage area
- Circle represents an AP coverage area

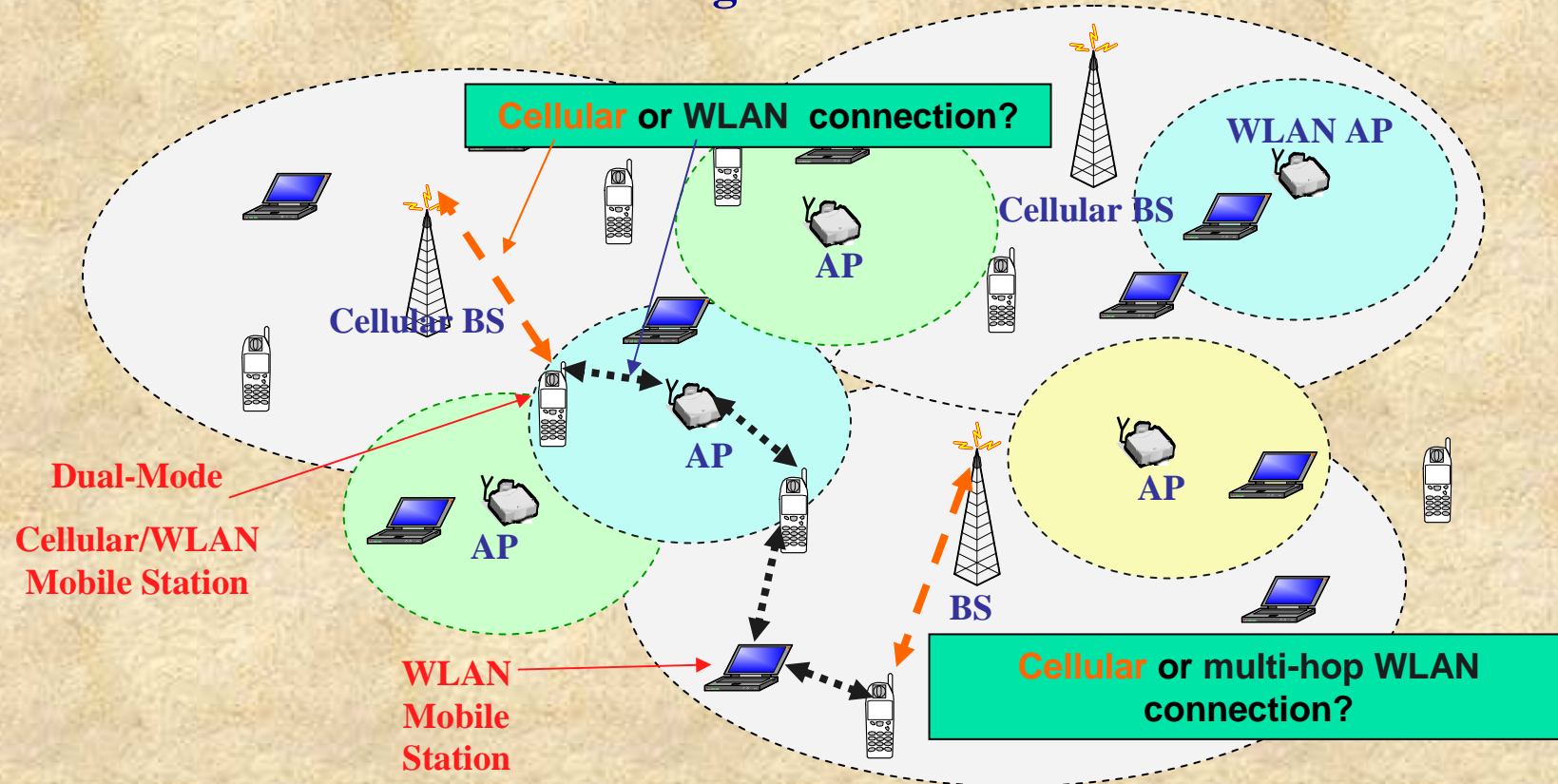


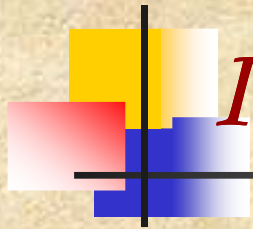
Ten possible Connection Alternatives

- ❑ A and B can communicate through the cellular interface
- ❑ A and B can be connected through one WLAN AP in the single-hop mode
- ❑ A and B can communicate with single-hop mode to their APs and these APs are interconnected through a fixed network
- ❑ A and B can use the WLAN interface in the ad hoc mode to communicate directly or through multiple hops
- ❑ A can use the WLAN interface in the ad hoc mode to connect to a Gateway Node (GN), which can establish a connection to B through a cellular BS in the single-hop mode
- ❑ A can use its WLAN interface in the ad hoc mode to connect to a GN, which can establish a connection to B through a WLAN AP in the single-hop mode
- ❑ Both A and B are out of the coverage of an AP, but they can connect using the multi-hop ad hoc mode by identifying the corresponding GNs C and D that can communicate through the AP
- ❑ Both A and B are out of the coverage of WLAN APs, but they can connect using the multi-hop ad hoc mode by identifying corresponding GNs C and D that can communicate through the fixed infrastructure (i.e., CN) in the single-hop mode
- ❑ A and B are using the cellular and the WLAN interfaces, respectively, and the corresponding BS and AP are connected through the fixed network CN
- ❑ A is using its WLAN interface (via multi-hop) to connect to a GN C that is connected to the BS, and this BS is connected through the CN to the AP that provide connectivity to the destination terminal B through the GN D

Problem Statement

- How to establish and manage connections between any two mobile stations in a heterogeneous networking environment?
 - How to discover connectivity alternatives available?
 - How to select the best connectivity alternatives?
 - How to establish and manage end-to-end connections?





Integrated Architectures for HWNs

Existing architectures and protocols considering Single-hop and Multi-hop

operation modes:

- ❑ **UCAN**
- ❑ **Two-hop-Relay**
- ❑ **iCAR**
- ❑ **HWN**
- ❑ **MCN**
- ❑ **A-GSM**
- ❑ **ODMA**
- ❑ **MADF**
- ❑ **SOPRANO**
- ❑ **CAMA**
- ❑ **Two-Tier Het MANET**
- ❑ **...**

Design Goals:

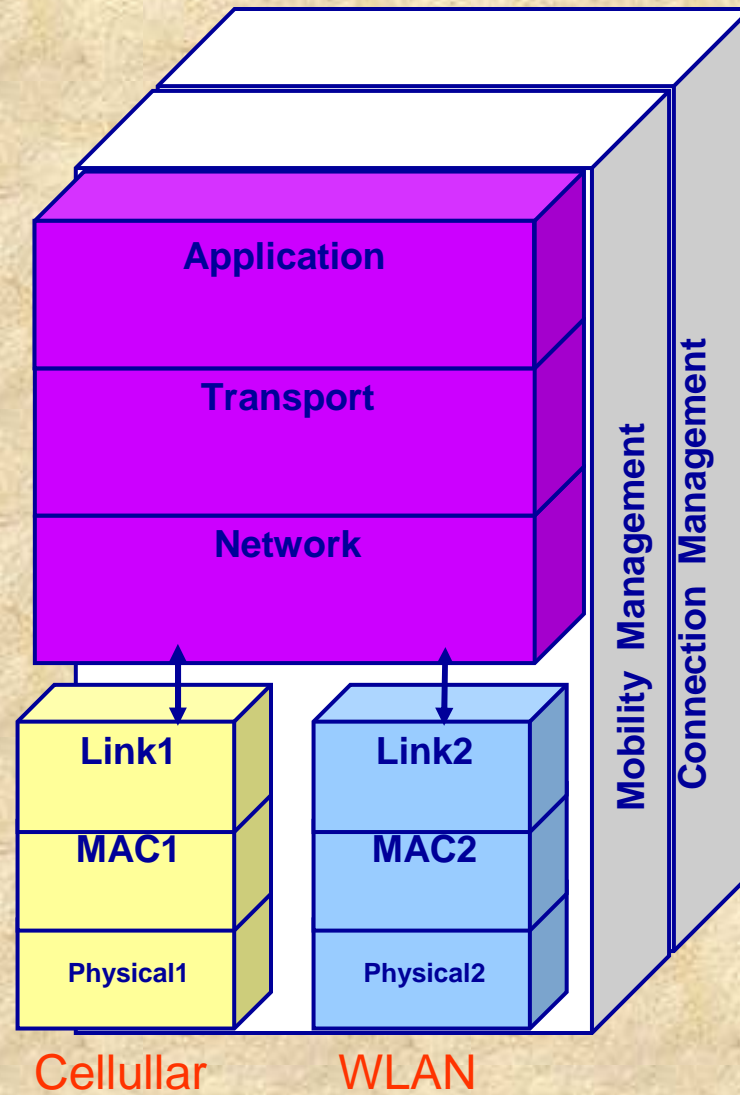
- **Improve cellular system's capacity (UCAN, Two-Hop-Relay, SOPRANO, HWN, MCN, ODMA)**
- **Improve cellular system's coverage (A-GSM, Two-Hop-Relay)**
- **Load balance between cells (iCAR, MADF)**
- **Provide Internet connectivity to MANETs (CAMA, Two-tier Het. MANET Architecture)**



Design Factors

- **Three unique features significantly affect the design of integrated solutions**
 - **Availability of multiple interfaces for a MH**
 - **Integration of cellular networks**
 - **WLANs, and multi-hop communication (i.e., MANETs)**
- **Several questions need to be addressed in order to provide an integrated, transparent and self-configurable service**
 - **What technology (or communication interface) to select to start a connection**
 - **When to switch an ongoing connection from one interface to another (i.e., vertical handoff)**
 - **How to select transmission power for a given communication interface, co-channel interference, topology discovery and route creation, mobility and handoff management, and load balancing**
- **Some of these questions have been addressed by researchers**
- **However, none of the existing models incorporate all these design factors**
- **Answer depends on the MH's capabilities, on the connectivity options available, on the user's mobility profile, on the QoS expected, and on the service cost**
- **Decision of what interface to use should be automatically taken by the system**
- **Selection of a given technology or decision to perform a vertical handoff can be used to enhance the overall system performance**

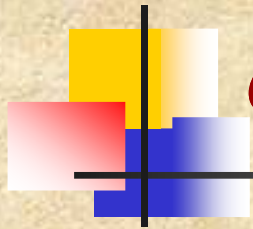
Dual Mode Terminals- Protocol Stack





Physical Layer

- **MHs equipped with multiple network interfaces can access multiple networks simultaneously**
- **Even though SDR based MHs are not fully capable of simultaneously accessing multiple wireless systems, discovering access networks need to be performed**
- **If MH is connected to a cellular network that is also within the coverage area of an 802.11b AP; the network or the MH needs be able to switch from cellular to WLAN**
- **In a heterogeneous environment, different wireless technologies may be operating in the same frequency band, and it is critical that they must coexist friendly without degrading the performance of each other**
- **For MHs far away from their APs, for example, the multi-hop communication links may result in less interference than direct transmission to the AP**
- **However, the capacity of AP decreases considerably, as a result of multi-hop, if MHs are close to the AP**
- **In a direct transmission from a MH to a BS or an AP, only a single frequency channel is required, whereas in the multi-hop connection from the same MH to the same BS**
- **Power control techniques have been applied to limit interference in CDMA-based cellular networks and MANETs**



Physical Layer ctd...

Open research issues:

- **Efficient design of SDR based MSs that switch between different technologies**
- **Cognitive and agile radios**
- **Frequency planning schemes for BSs/APs that could satisfy resource constraints while increasing the spectrum utilization**
- **Interference mitigation techniques between various wireless access technologies**
- **Note that modulation techniques and coding schemes will always be among the physical layer design challenges**



Data Link Layer

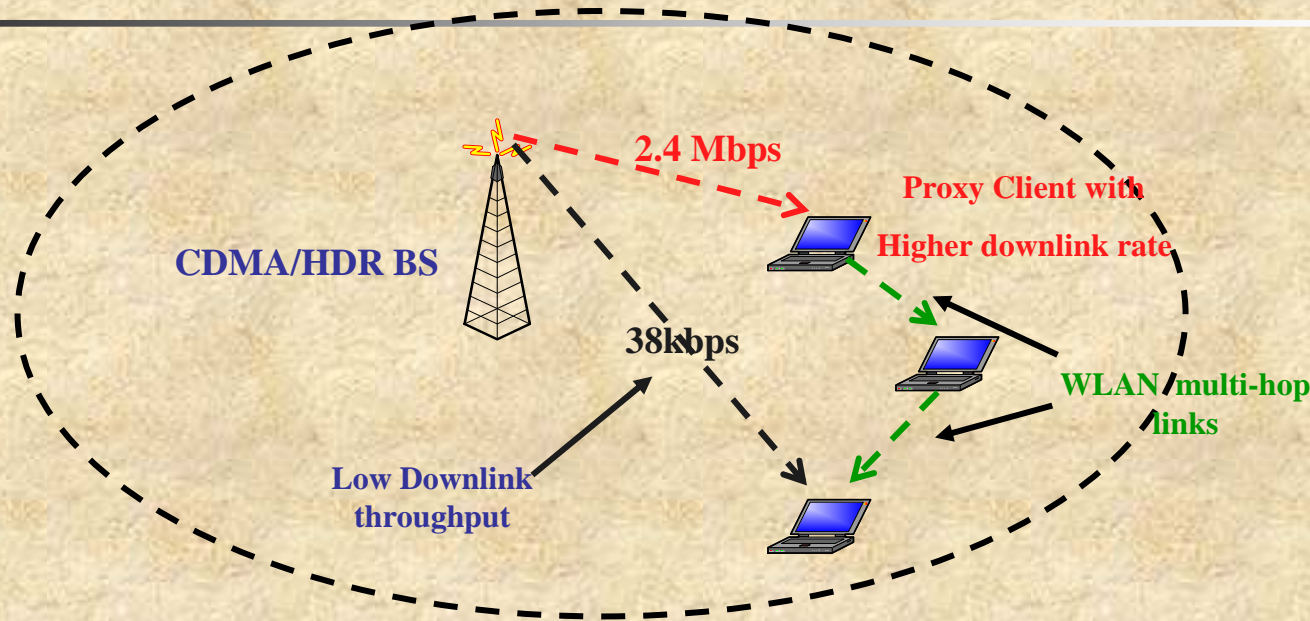
- Data link layer can be divided into logical link control (LLC) layer and MAC layer
- The MHs will be able to use a centralized MAC, such as TDMA or CDMA for a cellular network, or a distributed random access scheme in an IEEE 802.11 WLAN
- Data rate in the cellular interface can reach up to 2.4 Mbps while the 802.11b interface can provide up to 11 Mbps and the IEEE 802.11a/g standards support up to 54 Mbps
- When two MHs are communicating through multiple intermediary hops in the ad hoc mode, the performance can be even worse due to random access problems in each intermediary hop
- Mechanisms such as power control MAC protocols and MAC-based route selection can be used to improve the performance
- Although integration of heterogeneous technologies will not be performed at Link and MAC levels, these layers can provide useful information to upper layers
- An end-to-end connection can involve a sequence of several different Link and MAC layer connections
- Security is also an important issue to be considered at the Link/MAC level
- *Open Research Issues*
 - Design of efficient Link and MAC layers protocols for MANETs and WLANs that support different QoS levels
 - Channel management schemes in cellular networks that considers different categories of traffic and results in low call blocking and handoff failure (call dropping) probabilities
 - Link/MAC layer security



Network Layer

- Multiple interfaces of MHs can have different physical and MAC layer protocols, and need to be taken into account
- Routing problem also inherits all the issues related to multi-hop routing in MANETs, such as frequent route changes due to mobility, higher control overhead to discover and maintain valid routes, higher end-to-end delay, and limited end-to-end capacity due to problems at the lower layers
- Some existing solutions limit the number of multi-hops to a maximum of 2 or 3
- Integrating MANETs with single-hop networks is motivated by providing connectivity to MHs that are out of fixed BS/APs coverage using GNs
- Network layer must have mechanisms to allow these nodes in a MANET to find such gateways and to allow the MHs to correctly configure their IP addresses
- Network layer has to discover the integrated topology and find the best route between any source and destination pair
- Several metrics can be used to define the best route, including number of hops, delay, throughput
- *Integrated Architectures*: Several architectures and hybrid routing protocols have been proposed such as UCAN, Two-Hop-Relay, 1-hop and 2-hops Direct Transmission, HWN, MCN, iCAR, MADF, A-GSM, ODMA, SOPRANO, CAMA, and the Two-Tier Heterogeneous MANET Architecture

UCAN (Unified Cellular and Ad hoc Net.)



- Dual-Mode (WLAN + CDMA/HDR) MSs inside the coverage area of a HDR BS
- MSs try to discover proxy clients with better downlink signal quality to improve the downlink throughput
- The proxy clients forwards the downlink traffic to the destination MS through the WLAN interface
- Proxies are discovered inside a 2-hop neighborhood
- Optimization goal: Improve downlink traffic throughput

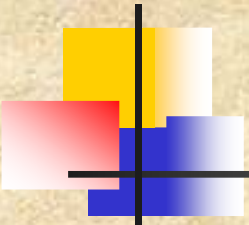


1-hop and 2-hops Direct Transmission

- Hybrid protocols is introduced for integrating single-hop and multi-hop operation in a WLAN environment, thereby
- Combines the strengths of the two models to solve problems
- These protocols can be used in a scenario similar to (8) in Figure 11.2
- Several control messages are introduced for multi-hop operation as well as to allow MHs to discover GNs (called agents) to connect to an AP
- If the receiver can no longer directly hear the sender's signal, the connection can be switched to the 2-hop-direction transmission mode
- However, if no sender's neighbor is accessible from the new receiver's position, they still can use the AP-oriented communication mode
- Hence, two communicating MHs can be in one of the three modes

Hybrid Wireless Network Architecture (HWN)

- This allows each cell (BS) to select the operation mode between a typical single-hop for sparse topologies or the ad hoc mode for dense topologies
- It is assumed that all MHs have GPS capabilities and send periodically location information to the BS
- The BS runs an algorithm to maximize throughput
- If the current operation mode is the ad hoc one, the BS compares the achieved throughput with $B/2N$, where B is the achievable bandwidth per cell and N is the number of MHs per cell
- BS periodically broadcasts minimum transmission power required to keep the network connected in the ad hoc mode
- Two drawbacks are: the minimum power used in the ad hoc mode can lead to disconnected topologies due to mobility, and ongoing connections are broken during the switching period
- Centralized mode selection for all the connections may not optimize the cell performance



Multi-Hop Cellular Network Architecture (MCN)

- All cells use the same data and control channels
- MHs and BS data transmission power is reduced to half of the cell radius to enable use of the same channel
- The transmission power in the control channel is corresponding to the cell radius and the MHs use this channel to send information about their neighbors to the BS
- Nodes recognize their neighbors using a contention-free beacon protocol and send their neighbors table to the BS
- When a MH wants to connect to a given destination, it sends a route request to the BS in the control channel
- BS finds the shortest path between the source and the destination
- Upon receiving the route reply, the source node inserts the route into the packet and begins its transmission
- When a node detects that the next hop is unreachable it sends a route error packet to the BS and buffers the current packet
- The BS responds with a route reply to the node that generated the route error and also sends a correct route packet



iCAR and MADF

iCAR

- Ad hoc relay stations (ARSs) are equipped with two interfaces, one to communicate with the cellular BSs and another to communicate in the ad hoc mode with other ARSs
- ARSs nodes can have limited mobility controlled by the cellular MSC
- Uses ARS to balance the traffic load between cells
- The ARSs can divert the traffic from an overloaded cell to an un-congested one
- Three basic relaying strategies can be used when a new call is originated in a congested cell: The primary relaying is when a MH A is originating a call in cell X and it can connect directly to a nearby ARS, which can divert the call to a neighboring cell Y
- When there is no ARS available to MH A, another ongoing call in cell X, let say MH C, can be transferred to a neighboring cell using another ARS, in order to free up a channel to be used by MH A (secondary relaying).
- If any of these two approaches can not be used, the third option, the cascade relaying, is to divert a call in cell Y to another cell Z, such that one of the ongoing call in the originating cell X, can be transferred to Y, and the new call is accepted in cell X
- This scheme also increases the coverage of the cellular network



iCAR and MADF

Mobile-assisted Data Forwarding (MADF)

- This achieves the load balance between cells by forwarding part of traffic in an overcrowded cell to some free cells
- Unlike iCAR, traffic forwarding in MADF is achieved by using MHs as relaying nodes that are located between overloaded (hot) cells and free (cold) ones
- Relaying MHs share a number of forwarding channels
- If the packet delay is high, the MH stops forwarding and requests BS for forwarding data packets to another neighboring cold cell
- If the hot cell returns to low traffic, the MH may stop its MADF forwarding and then redirects packets back to its own cell
- If MHs in a hot BS are far away from one another, the same forwarding-channels can be reused by two MHs to forward data to different neighboring BSs without interference
- Throughput in a hot cell surrounding by some cold cells can be significantly improved
- The advantage of MADF over iCAR is that there is no need for additional devices



A-GSM and ODMA

A-GSM (Ad hoc GSM) architecture

- **It allows GSM dual-mode terminals to relay packets in the MANET mode and provide connectivity in dead spot areas, thereby increasing the system capacity and robustness against link failures.**
- **The dual-mode terminals in are equipped with a GSM air interface and a MANET interface**
- **The terminals have an internal unit called DIMIWU (Dual-mode Identity and Internetworking Unity), which is responsible for performing the physical and MAC layer protocols adaptation required for each air interface**
- **At the link layer, the A-GSM mode uses an adaptation of the GSM Link Access Protocol for D channel (LAPDm)**
- **In the beacon message, a relay node can include the BS it can connect to, as well as the respective number of hops required to reach the BS**
- **The drawback of this proactive gateway discovery scheme is the high control overhead**
- **The resource manager decides whether a relaying request should be accepted**
- **A busy flag could reduce the number of beacon messages sent while the continuous transmission of beacons is used to keep information about the quality of the links between a node and its neighbors**

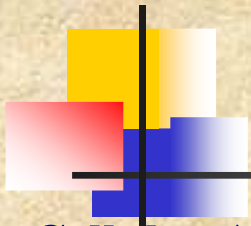
ODMA (Opportunity Driven Multiple Access) scheme

- **Both solutions integrate multiple accesses and relaying function to support multi-hop connections**
- **The ODMA breaks a single CDMA transmission from a MH to a BS, or vice versa, into a number of smaller radio-hops**
- **However, the ODMA does not support the communications for the MHs that are outside the coverage of BSs**



Self-organizing Packet Radio Ad hoc Network with Overlay (SOPRANO)

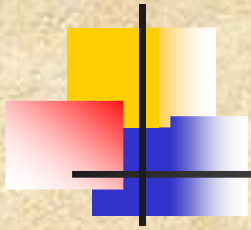
- **Investigates some of the techniques by which the capacity of cellular network can be enhanced**
- **Advocates six steps of self-organization for the physical, data link, and network layers to optimize the network capacity**
- **Multi-user detection is also suggested for the physical layer**
- **If transmissions are directed to a node with multi-hop, clever frequency channel assignments can significantly reduce the interference**
- **In the network layer, multi-hop routing strategy must take into account the traffic, the interference and the energy consumption**



CAMA

Cellular Aided Mobile Ad hoc Network (CAMA) architecture

- Underlying goal to enhance the performance of MANETs, with the aid of the existing cellular infrastructure
- This concept is slightly different as the cellular network is used only to control the operation of the MANET by providing authentication, routing and security
- Only control data is sent to the cellular network
- The CAMA agents perform route discovery using a centralized position-based routing scheme, called multi-selection greedy positioning routing (MSGPR)
- MHs are assumed to have GPS (Global Positioning System) capabilities
- All MHs are assumed to be under the cellular coverage, such that the CAMA agents are provided with information about the entire MANET
- However, the dynamic nature of MANETs can not always assure QoS guarantees required by multimedia services
- The connectivity between the MANET and the Internet is provided by special MHs (Gateways or APs) connected to the fixed network
- CAMA uses the cellular infrastructure to improve the performance of MANETs
- This concept could be extended to provide other control operations in the MANET



Two-Tier Heterogeneous MANET Architecture

Two-Tier Heterogeneous Mobile Ad hoc Network

- **Considers MHs operating as in dual-modes**
- **MHs operating in the MANETs form the lower tier, while the dual-mode gateways form the second tier of the architecture**
- **Load balancing issues come into picture**
- **Several gateway selection schemes are proposed**
- **Similarly to CAMA, the Two-Tier Heterogeneous MANET architecture does not provide services to cellular users**
- **The destination or the source node is always in the fixed network**

Open Research Issues

- **Design of integrated and intelligent routing protocols is largely open for research**
- **Scalability in multi-hop routing without drastically increasing the overhead**
- **The impact of additional routing constraints and requirement needed by MSs and networks**



Transport Layer

- Performance degradation of the TCP protocol is the most important issue in any wireless transport layer
- Transport protocol has also to handle the high delays involved in connection switching from one interface to another
- Basic problem is how to maintain a TCP connection when a MH changes its IP address as it enters a new access network
- Due to firewalls, server migration support may be required when the MH cannot access the original application server
- Also, the overlap of coverage between different access technologies can be exploited to improve the aggregate connection's bandwidth.
- Most approaches enhance TCP performance in wireless networks by providing feedback information about the causes of the errors
- A receiver centric approach is developed such that the receiver closer to the wireless last-hop can obtain more accurate information about causes of the losses
- In the case of server migration, the overhead required to transfer connection state information from one sever to another is minimized
- An extension of the RCP protocol for host with multiple interfaces, called R2CP (Radial RCP) also proposed to support seamless handoffs and bandwidth aggregation
- R2CP aggregates multiple RCP connections into one abstract connection for the application layer
- The protocol keeps multiple states at the host according to the number of active interfaces.
- Then, in a vertical handoff, the application can continue transmitting and receiving data in the old interface before the new connection is established

Open Research Issues

- Design of new transport protocol or adapt the existing protocols to take delays into account in vertical handoffs
- Implement server migration without interrupting ongoing connections



Application Layer

- Applications should have only an access point to the transport layer and network services
- Network layer needs to exploit multiple access technologies
- This provides different kinds of application services to the users
- MHs should be able to discover and inform the user availability of such service
- Some kind of virtual service manager is needed to provide information of services available in the fixed network part (through BS or AP) to MH
- Design of charging and/or rewarding schemes in the application layer is a critical issue
- Another fundamental problem is end-to-end security

Open Research Issues

- End-to-End security
- Service Discovery mechanisms
- Credit charging and rewarding mechanisms



Mobility and Connection Management

- **Mobility and connection management are two control planes that provide topology discovery, detect available Internet access, as well as support vertical handoffs**
- **But, the mobility and connection management functionalities cannot be separated**

Internet Connectivity

- **Current cellular networks (2.5 and 3G) provide IP services based on the IPv4 protocol**
- **In WLANs, APs can act as Internet Gateways (IGW) to MHs**
- **Future heterogeneous networks will be based on IPv6**
- **APs can also provide Internet connectivity and perform mobility management functions for those “out of coverage” MHs**
- **The gateway discovery process can be implemented in a proactive, reactive or hybrid fashion**
- **The process of discovering an AP that acts as IGW, can also be considered as the process of discovering another MH**



Mobility and Connection Management

- **Two types of handoffs**
 - **Horizontal handoffs**
 - **Vertical handoffs**
- **The horizontal handoffs can be handled by the cellular network components at the link layer and at the network layer, the Mobile IP (Mobile IPv4 and IPv6) protocol can be used to support macro and global mobility**
- **The Mobile IP provides an effective solution for macro and global mobility management**
- **Several mobility management schemes have been proposed to reduce the handoff latency in the micro-mobility environments**
- **In the case of vertical handoffs, two basic issues have to be considered:**
 - **When to start the handoff process?**
 - **How to redirect the traffic between interfaces?**
- **The redirection process can be performed in a seamless or a reactive way**
- **No integrated solution exists to handle all the possible types of vertical handoffs in a heterogeneous environment, as the shown in Figure 11.1**
- **In general, the vertical handoff latency can be characterized by three components:**
 - **Detection period is the time taken by the MH to discover an IGW;**
 - **Address configuration interval is the time taken by a MS, after detecting an IGW, to update its routing table, and assign its interface with a new care-of-address (CoA) based on the prefix of the new access network**
 - **Network registration time is the time taken to send a binding update to the home agent as well as the correspondent node, to the time it takes to receive the first packet on the new interface**



Reactive IGW discovery

- Some schemes have been proposed to reduce the handoff latency in a GPRS/WLAN scenario:
 - Fast router advertisements
 - Route advertisements caching
 - Binding update simulcasting
 - Smart buffer management using a proxy in GPRS
 - Layer-3 soft handoff
- An extension of the Mobile IPv6 protocol is proposed where MMI (Multiple Interface Management) redirects traffic flows between two interfaces
- When MS wants to redirect its ongoing flows from the source interface I_1 to the target interface I_2 , the node simply sends a Binding Update message to its home agent (HA_1)
- This allows the home agent for I_1 to register an association between IP_1 and IP_2 in its binding cache
- In case of horizontal handoff on the interface I_2 to a new subnet, both home agents HA_1 and HA_2 need to be informed of the new Care-of-Address IP_3

Open Research Issues

- Efficient gateway discovery protocols to integrate MANETs with fixed network components
- Development of new mobility and connection management approaches to reduce the delay during vertical handoffs



Trigger events for vertical handoffs

Trigger Event	Description
Interface down	An interface currently used fails, so the MH cannot receive its flows anymore
Interface up	A new interface is available, e.g., the node enters the coverage area of a new access network
Horizontal handoff procedure	As a horizontal handoff procedure in the currently used interface is started, the node can redirect the traffic to another interface to reduce undesirable effects of the high delay involved in the handoff process
Change in network capabilities	The QoS provided by one interface improves or degrades (coverage, data rate, power consumption, etc.)



Comparison of the Integrated Architectures

- **A-GSM, ODMA and iCAR introduce ad hoc mode in a cellular system but they do not consider the possibility of integrating WLAN APs**
- **On the other hand, the 1-hop and 2-hop direct transmission protocols are especially designed to integrate single-hop and MANET mode**
- **The HWN and MCN architectures also focus on the integration of a generic single-hop mode and MANETs, and they do not consider dual-mode terminals**
- **The UCAN and Two-Hop-Relay architectures consider the most general scenario**
- **However, the results with these schemes assume that all nodes are dual-mode and are under a single cellular BS coverage and no WLAN AP is included in the evaluation**

Comparison of Integrated Architectures

Architecture	Operation modes considered	Main Optimization goal	Mobile user Stations	Supported Scenarios or its Variation in Fig.2	Support of out of coverage MSs	Connection mode/ Gateway Discovery
<i>A-GSM</i>	Cellular - MANET	Coverage, transmission power reduction and capacity	Dual-mode	(1), (5)	Yes	GNs send beacon (advertise) messages (proactive scheme)
<i>ODMA</i>	Cellular - MANET	Transmission power reduction and BS capacity	Dual-mode	(1), (5) but all MHs are under coverage of BSs	No	There is no concept of gateway, every node can relay packets, and the routing decision is based on the signal quality
<i>iCAR</i>	Cellular - MANET	Load balance between BSs	Single-mode and Dual-mode	(1), (5)	No	The GN nodes are deployed in planned positions and the MH can only use 1-hop away GNs.
<i>UCAN</i>	Cellular - WLAN - MANET	BS throughput and user downlink data rate	Single-mode and Dual-mode	(1), (2), (3), (5) but all MHs are under coverage of BSs	No	MSs search for gateway nodes when their transmission rate decreases below a given threshold (proactive or reactive discovery)
<i>Two-Hop-Relay</i>	Cellular - WLAN - MANET	BS throughput	Single-mode and Dual-mode	(3), (5)-(8)	Yes	The GNs send advertising messages (proactive scheme)
<i>1-hop and 2-hops Dir. Trans.</i>	WLAN - MANET	Reliability to BS failures and handoffs	Single-mode	(3), (8)	Yes	Destination MH selects the connection mode, but MHs can act as gateways in case of APs failures
<i>HWN</i>	WLAN or Cellular - MANET	BS throughput	Single-mode	(1), (4)	No	BS selects the cell's operation mode
<i>MCN</i>	WLAN or Cellular - MANET	BS throughput	Single-mode	(1) - (4)	No	BS/AP selects the operation mode and execute a centralized routing algorithm
<i>MADF</i>	Cellular - MANET	Load balance between BSs	Single-mode	(1), (5)	No	Ad hoc routing protocol for routing discovery
<i>SOPRANO</i>	Cellular - MANET	BS Capacity	Single-mode	(1), (5)	No	Routing decision is based on minimum interference and energy
<i>CAMA</i>	Cellular - MANET	Improve MANET performance.	Single-mode and Dual-mode	(4), but with all MSs under cellular coverage	No	Gateways are used only to provide access to the CAMA agents in the cellular network
<i>Two-Tier Heterogeneous MANET</i>	Cellular - MANET	Connectivity MANETs with the Internet	Single-mode and Dual-mode	(5)	No	Several gateway selection schemes are provided to provide load balance among the gateways.



Comparison of Integrated Architectures

- ❑ A common goal of the integration schemes is to improve the capacity in the cellular-based (BS or AP) systems
- ❑ In A-GSM and ODMA, the reduction in the MH's transmission power is also identified as an advantage
- ❑ The main goal in CAMA is slightly different from other solutions
- ❑ The main focus of Two-Tier Heterogeneous architecture is to provide Internet connectivity to MANET users and provide connectivity for MHs
- ❑ All nodes are assumed to be under a BS or AP coverage in iCAR, UCAN, HWN and MCN
- ❑ ODMA achieves a capacity gain by reducing the interference level inside the cell
- ❑ The iCAR architecture uses multi-hop only to transfer connections between BSs, performing load balance
- ❑ HWN and MCN approaches assume that the cell can operate only in the cellular-based or the ad hoc mode
- ❑ Since different connections can have different QoS requirements, selecting transmission mode for each request seems to be the most suitable approach
- ❑ In UCAN, the GN (client proxy) for a given connection has to have a higher downlink rate than the other terminals in the multi-hop path
- ❑ GNs capabilities and responsibilities are not the same in all cases
- ❑ "Out of coverage" MHs have to find a gateway in order to join the network, which involves tasks as registration, authentication and addressing
- ❑ However, despite of the gateways functionalities, the network has to provide some means for the MHs to discover them in a proactive or reactive fashion
- ❑ In UCAN, the MH starts the search for the gateway as needed (reactive approach)
- ❑ In iCAR, only 1-hop transmissions are allowed between a typical MH and a GN (called ASR), such that the MH can search for a gateway among its one-hop neighbors
- ❑ There is no concept of GN in ODMA, HWN and MCN



Conclusions and Future Directions

- **Future networking ought to integrate a myriad of heterogeneous terminals and access technologies**
- **Accessibility alternatives provide different QoS and coverage levels**
- **Designing heterogeneous network that provide QoS guarantees is extremely complex and challenging**
- **Open research issues discussed at each layer of the protocol stack**
- **The fixed infrastructure components, i.e., the BSs and APs, are expected to play an important role**
- **Another fundamental task of the network layer is to support seamless horizontal and vertical handoffs**
- **Furthermore, service discovery and security mechanisms need to be provided**