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Internal Assessment Test-II								
Sub:	Optical and Wireless Communication						Code:	21EC72
Date:	19/11/2024	Duration:	90 mins	Max Marks:	50	Sem: 7th	Branch:	ECE(A,B,C,D)
Answer any **FIVE FULL** Questions								

		Marks	OBE CO	OBE RBT
1.	Explain the construction and working of fiber Bragg grating. Also mention its applications in WDM.	[10]	CO2	L2
2.	Give an overview of wavelength division multiplexing and its standards.	[10]	CO2	L2
3.	Explain the key differences between 1G, 2G, 3G, 4G and 5G mobile communication standards.	[10]	CO3	L2
4.	Identify at least three factors that can affect signal propagation in a wireless medium. Explain how each factor can occur and/or how it impacts propagation.	[10]	CO3	L3

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(a) directly away from the base-station transmitter
(b) directly towards the base-station transmitter
(c) in a direction which is 60 degrees to the direction of arrival of the transmitted signal
(d) in a direction perpendicular to the direction of arrival of the transmitted signal.

6. Explain the following cellular terminologies: [10] CO3 L2
(a)Cell
(b)Footprint
(c)Cell cluster
(d)Cluster size and system capacity.

7. Explain how the following multiple access techniques are used in wireless communications: [10] CO4 L2
(a) FDMA
(b) TDMA

CI CCI HoD/ECE

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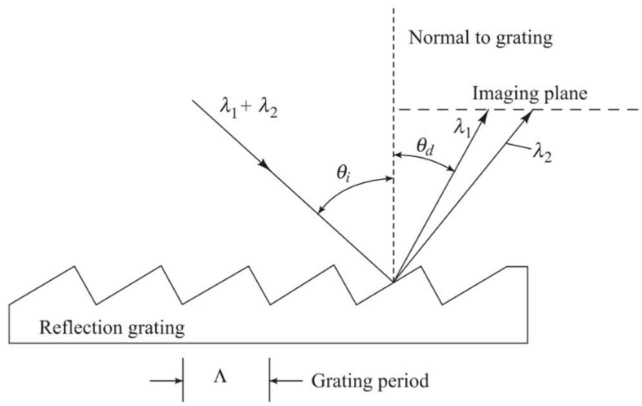
CI CCI HoD/ECE

1. Explain the construction and working of fiber Bragg grating. Also, mention its applications in WDM.

A grating is an important element in WDM systems for combining and separating individual wavelengths. A grating is a periodic structure or perturbation in a material. This variation in the material has the property of reflecting or transmitting light in a certain direction depending on the wavelength. Thus, gratings can be categorized as either reflecting or transmitting gratings.

Here, theta i is the incident angle of the light, theta d is the diffracted angle, and L is the period of the grating (the periodicity of the structural variation in the material). In a transmission grating consisting of a series of equally spaced slits, the spacing between two adjacent slits is called the pitch of the grating. Constructive interference at a wavelength l occurs in the imaging plane when the rays diffracted at the angle satisfy the grating equation given by

$$\Lambda\,(\sin\theta_i - \sin\theta_d) = m\lambda$$



Here, m is called the order of the grating. In general, only the first-order diffraction condition m=1 is considered. A grating can separate individual wavelengths since the grating equation is satisfied at different points in the imaging plane for different wavelengths.

A Bragg grating constructed within an optical fiber constitutes a high-performance device for accessing individual wavelengths in the closely spaced spectrum of dense WDM systems. Since this is an all-fiber device, its main advantages are low cost, low loss (around 0.3 dB), ease of coupling with other fibers, polarization insensitivity, low-temperature coefficient (< 0.7 pm/°C for a thermal device), and simple packaging. A fiber grating is a narrowband reflection filter that is fabricated through a photo imprinting process. The technique is based on the observation that germanium-doped silica fiber exhibits high photosensitivity to ultraviolet light. This means that one can induce a change in the refractive index of the core by exposing it to ultraviolet radiation such as 244 nm.

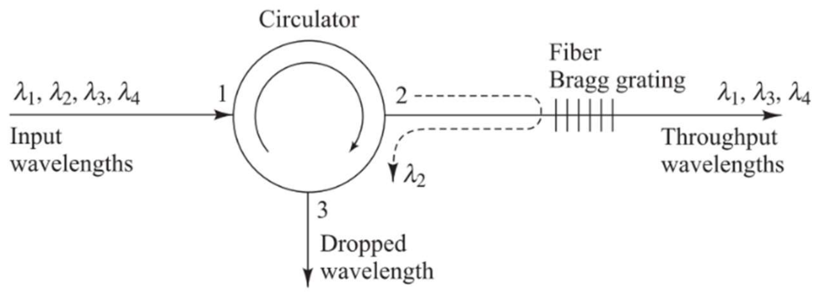
The imprinted grating can be represented as a uniform sinusoidal modulation of the refractive index along the core:

$$n(z) = n_{core} + \delta n\left[1 + \cos\left(\frac{2\pi z}{\Lambda}\right)\right]$$

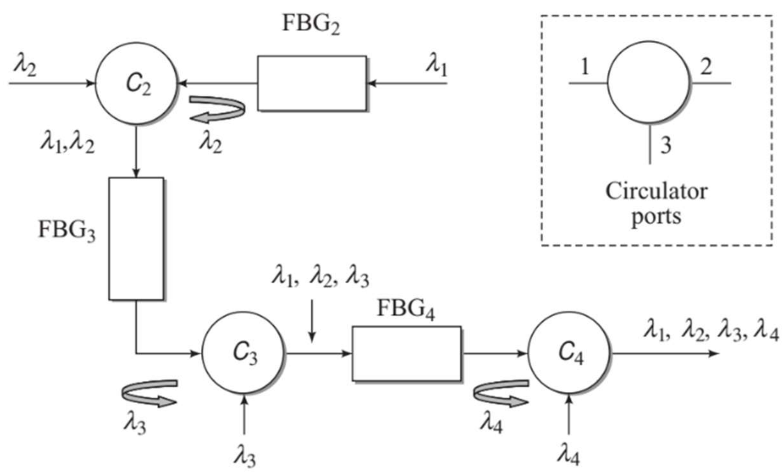
The maximum reflectivity R of the grating occurs when the Bragg condition holds; that is, at a reflection wavelength where

$$\lambda_{\text{Bragg}} = 2\Lambda\, n_{\text{eff}}$$

FBG Applications:
Mux, DMux



Simple concept of a demultiplexing function using a fiber grating and an optical circulator

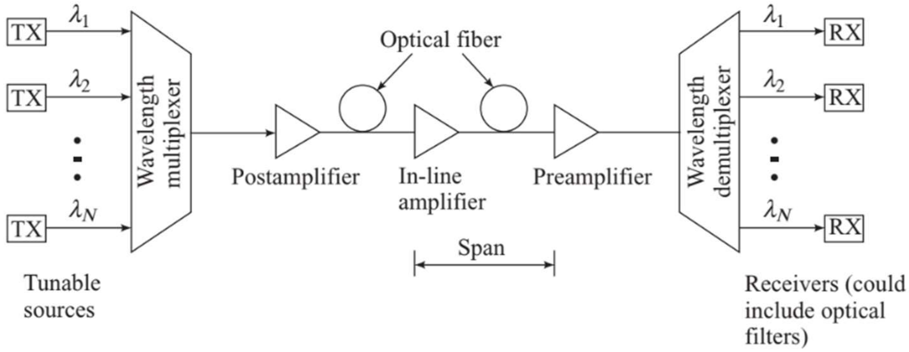


Multiplexing of four wavelengths using three FBG devices and three circulators

2. Give an overview of wavelength division multiplexing and its standards.

WDM: many independent wavelength channels spaced less than a nanometer apart could be placed on the same fiber. A characteristic of WDM is that the discrete wavelengths form an orthogonal set of carriers that can be separated, routed, and switched without interfering with each other. This isolation between channels holds as long as the total optical power intensity is kept sufficiently low to prevent nonlinear effects.
The implementation of sophisticated WDM networks requires a variety of passive and active devices to combine, distribute, isolate, and amplify optical power at different wavelengths. Passive devices require no external control for their operation, so they are somewhat limited in their application flexibility. These components are mainly used to split and combine or tap off optical

signals. The wavelength-dependent performance of active devices can be controlled electronically or optically, thereby providing a large degree of network flexibility. Active WDM components include tunable optical filters, tunable sources, and optical amplifiers.



l *Implementation of a typical WDM network containing various types of optical amplifiers*

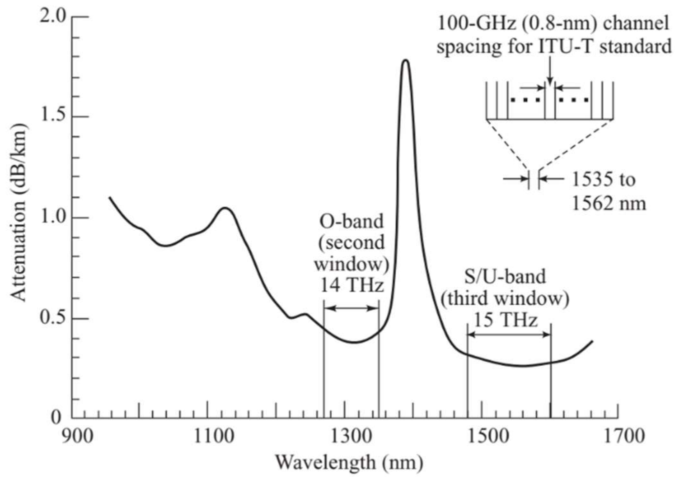
At the transmitting end, there are several independently modulated light sources, each emitting signals at a unique wavelength. Here a multiplexer is needed to combine these optical outputs into a continuous spectrum of signals and couple them onto a single fiber. At the receiving end a demultiplexer is required to separate the optical signals into appropriate detection channels for signal processing.

The operational frequency band allocated to a particular light source normally ranges from 25 to 100 GHz (or equivalently, a spectral band of 0.25 to 0.8 nm at a 1550-nm wavelength). The exact width of the frequency or spectral band that is selected needs to take into account possible drifts in the peak wavelength emitted by the laser and temporal variations in the wavelength response of other link components. These parameter changes can result from effects such as component aging or temperature variations.

WDM Standards:

Since WDM is essentially frequency division multiplexing at optical carrier frequencies, the WDM standards developed by the International Telecommunication Union (ITU) specify channel spacing in terms of frequency. A key reason for selecting a fixed frequency spacing, rather than a constant wavelength spacing, is that when locking a laser to a particular operating mode, it is the frequency of the laser that is fixed.

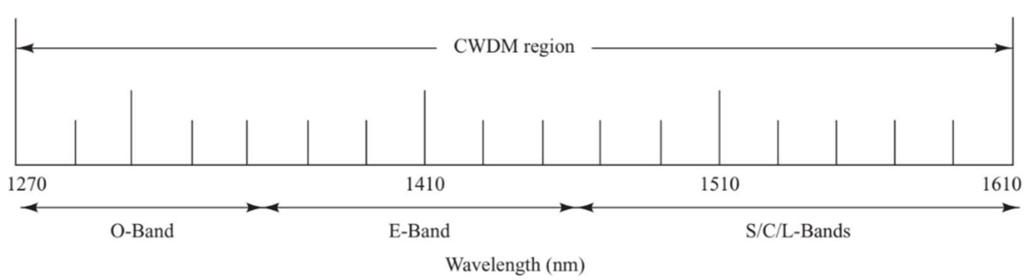
Recommendation G.692 was the first ITU-T specification for WDM.11 This document specifies selecting the channels from a grid of frequencies referenced to 193.100 THz (1552.524 nm) and spacing them 100 GHz (about 0.8 nm at 1550 nm) apart. Suggested alternative spacings in G.692 include 50 GHz and 200 GHz, which corresponds to spectral widths of 0.4 and 1.6 nm, respectively, at 1550 nm. Historically the term, dense WDM (DWDM) generally referred to small wavelength separations, such as those denoted by ITU-T G.692.



The transmission-band widths in the O- and C-bands (the 1310-nm and 1550-nm windows) allow the use of many simultaneous channels for sources with narrow spectral widths. The ITU-T G.692 standard for WDM specifies channels with 100-GHz spacings.

In 2002 the ITU-T released Recommendation G.694.1, which is aimed specifically at DWDM. This document specifies WDM operation in the S-, C-, and L-bands for high-quality, high-rate metro area network (MAN) and wide area network (WAN) services. It calls for narrow frequency spacings of 100 to 12.5 GHz (or, equivalently, 0.8 to 0.1 nm at 1550 nm). This implementation requires the use of stable, high-quality, temperature-controlled, and wavelength-controlled (frequency-locked) laser diode light sources. For example, the wavelength-drift tolerances for 25-GHz channels are ± 0.02 nm.

The concept of coarse WDM (CWDM) emerged from the combination of the production of full-spectrum (low-water-content) G.652C and G.652D fibers, the development of relatively inexpensive optical sources, and the desire to have low-cost optical links operating in access networks and local area networks. In 2002 the ITU-T released Recommendation G.694.2, which defines the spectral grid for CWDM. The CWDM grid is made up of 18 wavelengths defined within the range 1270 nm to 1610 nm (O- through L-bands) spaced by 20 nm with wavelength-drift tolerances of ± 2 nm. This can be achieved with inexpensive light sources that are not temperature-controlled.



The ITU-T Recommendation G.695 released in 2004 outlines optical interface specifications for multiple-channel CWDM over distances of 40 and 80 km. Both unidirectional and bidirectional systems (such as used in passive optical network applications) are included in the recommendation. The applications for G.695 cover all or part of the 1270-to-1610-nm range. The main deployments are for single-mode fibers, such as those specified in ITU-T Recommendations G.652 and G.655.

3. Explain the key differences between 1G, 2G, 3G, 4G and 5G mobile communication standards.

Mobile Technology	Launched Year	Services	Technologies	Speed	Frequency Bandwidth	Milestone
1G	1980s	Voice only	AMPS, NMT, TACS	2 Kbps	30 KHz	First Mobility Call
2G	1990s	Voice, SMS, slow data	GSM, CDMA	9.6 - 100 Kbps	200KHz	SMS introduced, roaming
3G	2000s	Voice, Video call, MMS	WCDMA, CDMA2000	2 to 21 Mbps	5 MHz	Speed in Mbps, Video Call
4G	2010s	Voice, High speed data, IoT	LTE	10 Mbps to 1 Gbps	1.4 MHz to 20 MHz	All IP, VoLTE, IoT
5G	2020s	Fast data, Massive IoT, low latency applications	NR	>1 Gbps	100 MHz to 1 GHz	Very high speed data, Low latency, mmWave
6G	2030s?	Ultra Fast data, Holographic call	?	~100 Gbps	1GHz to 100 GHz?	Tera Hertz frequency, Huge bandwidth

1G (First Generation):
Timeline: 1980s
Key Features: Analog cellular networks
Basic voice calling
Technology: AMPS (Advanced Mobile Phone System)
Frequency Bands: Primarily 800 MHz
Speed: Low data rates, primarily designed for voice communication
Use Cases: Voice calls with limited coverage and mobility.

2G (Second Generation):
Timeline: Early 1990s
Key Features: Digital networks (GSM, CDMA)
Introduction of SMS (Short Message Service)
Technology: GSM (Global System for Mobile Communications), CDMA (Code Division Multiple Access)
Frequency Bands: 900 MHz, 1800 MHz (GSM); 800 MHz, 1900 MHz (CDMA)
Speed: Up to 64 Kbps
Use Cases: Voice calls, SMS, limited data services.

2.5G (GPRS – General Packet Radio Service):
Timeline: Late 1990s
Key Features: Packet-switched data, basic internet.
Technology: GPRS
Frequency: Utilized existing 2G frequencies
Speed: Up to 144 Kbps
Use Cases: Basic mobile internet, email.

2.75G (EDGE – Enhanced Data Rates for GSM Evolution):
Timeline: Early 2000s
Key Features: Improved data rates compared to GPRS.
Technology: EDGE
Frequency: Utilized existing 2G frequencies
Speed: Up to 384 Kbps
Use Cases: Enhanced mobile internet, multimedia messaging.

3G (Third Generation):
Timeline: Early 2000s

Key Features: High-speed data transmission
Mobile internet access, video calling
Technology: UMTS (Universal Mobile Telecommunications System), CDMA2000
Frequency Bands: Varied (2 GHz range)
Speed: Several Mbps (up to 14.4 Mbps for UMTS)
Use Cases: Mobile internet, video calling, more advanced data services.

4G (Fourth Generation):
Timeline: Mid-2000s (commercial deployments in 2009)
Key Features:LTE (Long-Term Evolution) technology
High-speed broadband, low latency
Technology: LTE
Frequency Bands: Varied (700 MHz to 2.6 GHz and higher)
Speed: Up to several hundred Mbps (peak speeds)
Use Cases: Mobile broadband, HD video streaming, advanced mobile services.

5G (Fifth Generation):
Timeline: Commercial deployments started in 2019
Key Features: Massive data capacity
Low latency, high reliability
Network slicing, Massive MIMO, mmWave technology
Technology: NR (New Radio)
Frequency Bands: Sub-6 GHz and mmWave (24 GHz and above)
Speed: Multi-Gbps (peak speeds)
Use Cases: Enhanced mobile broadband, IoT, critical communication, augmented reality, virtual reality.

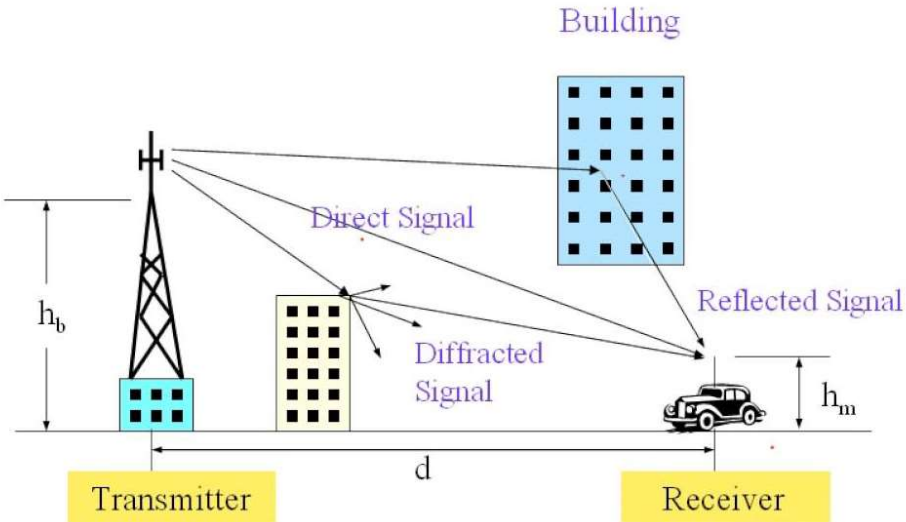
6G (Expected Future Generation):
Timeline: Anticipated in the 2030s
Key Features (Expected):Extremely high data rates (potentially terabits per second)
Ultra-low latency (sub-millisecond)
Advanced AI integration, quantum communication
Technology: Yet to be defined, expected to include breakthrough technologies
Frequency Bands (Expected): Terahertz frequencies
Speed (Expected): Terabits per second
Use Cases (Expected): Holographic communication, advanced augmented reality, AI-driven applications, immersive experiences

4. Identify at least three factors that can affect signal propagation in a wireless medium. Explain how each factor can occur and/or how it impacts propagation.

   Ans:

   The received signal always differs from the transmitted signal. Owing to the very small wavelength electromagnetic waves can be treated simply as optical rays, and thus three basic radio propagation mechanisms: reflection, diffraction, and scattering

- If a mobile unit has a clear line-of-sight condition with the cell-site then only reflection may have a significant effect whereas diffraction and scattering have minor effects on the received signal levels.
- If there is no clear line-of-sight condition, such as in an urban area at busy street level, then diffraction and scattering are the primary signal reception.



Reflection:

- Impinges on surfaces with various electrical properties
- Size of an object greater than the wavelength
- Fresnel reflection coefficient
- Upon reflection, the signal strength of the radio wave gets attenuated. It depends on many factors like the frequency of the radio waves, the angle of incidence, and the nature of the medium including its material properties, thickness, homogeneity, etc.
- Generally, higher frequencies reflect more than lower frequencies.
  - These reflected waves may interfere constructively or destructively with the receiver.
  - the vectorial addition of these multipath reflected signals produces an undetectable signal.

Diffraction:

- Diffraction occurs when the radio path between a transmitter and receiver is obstructed by a surface with sharp irregular edges.

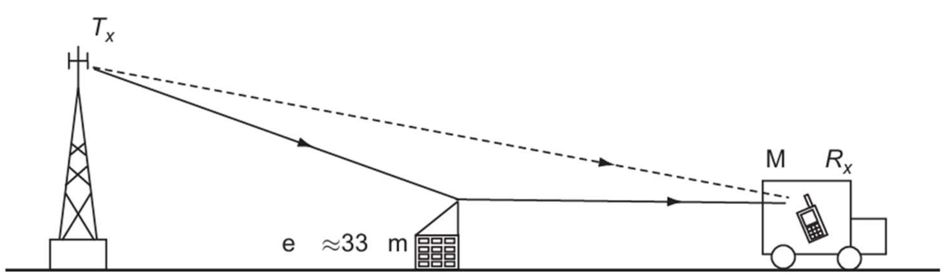


Fig. 2.3 | *Diffraction of a radio signal*

- Huygen’s principle: all points on a wavefront can be considered point sources for producing secondary wavelets that can combine to produce a new wavefront in the direction of propagation of the signal.
- Waves bend around the obstacle
- description of how a radio signal propagates around and over an obstruction: small signal fading
- results in propagation into shadow regions

<u>Scattering:</u>

- Scattering is a special case of reflection caused by irregular objects

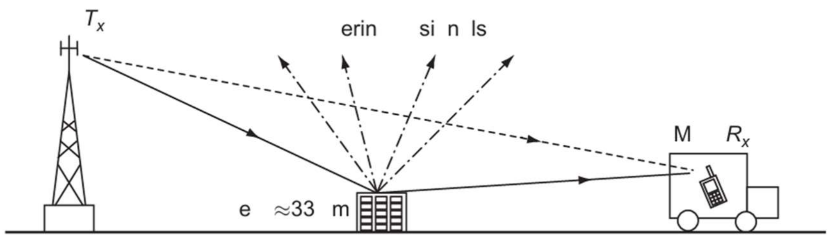


Fig. 2.4 | *Scattering of radio signal*

- Scattering occurs when the size of objects is comparable to or smaller than the wavelength of the propagating radio wave
- Results in Small scale fading

5. Consider a base-station transmitter operating at 900 MHz carrier frequency. For a mobile moving at a speed of 72 km/h, calculate the received carrier frequency if the mobile is moving
   (a) directly away from the base-station transmitter
   (b) directly towards the base-station transmitter
   (c) in a direction which is 60 degrees to the direction of arrival of the transmitted signal
   (d) in a direction perpendicular to the direction of arrival of the transmitted signal.

Solution

Carrier frequency of base station transmitter, $f_c = 900$ MHz (given)
Speed of the mobile, V_m = 72 km/h (given)
Or, $V_m = (72 \times 10^3)/3600 = 20$ m/s

***(a)** To calculate received carrier frequency when the mobile is moving directly away from the base-station transmitter*

Step 1. *In the given case,* $\theta = 180^\circ$, $\cos\theta = \cos 180^\circ = -1$

So the Doppler shift is negative.

Step 2. *Doppler frequency, or Doppler shift, is given by*

$f_d = (1/\lambda_c)\, V_m$ where $\lambda_c = (c / f_c)$

Or, $f_d = (f_c / c)\, V_m = (900 \times 10^6 \text{ Hz} / 3 \times 10^8 \text{ m/s}) \times 20$ m/s

Or, $f_d = 60$ Hz

Step 3. *The received carrier frequency at the mobile* $= f_c - f_d$

$= 900 \times 10^6 \text{ Hz} - 60$ Hz

$= 899.99994$ MHz

***(b)** To calculate the received carrier frequency when the mobile is moving directly towards the base-station transmitter.*

Step 4. *In this case,* $\theta = 0^\circ$, $\cos\theta = \cos 0^\circ = +1$.

So the Doppler shift is positive.

Step 5. *Doppler frequency or Doppler shift is given by*

$f_d = (f_c / c)\, V_m = (900 \times 10^6 \text{ Hz} / 3 \times 10^8 \text{ m/s}) \times 20$ m/s

Or, $f_d = 60$ Hz

Step 6. *The received carrier frequency at the mobile* $= f_c + f_d$

$= 900 \times 10^6 \text{ Hz} + 60$ Hz

$= 900.00006$ MHz

***(c)** To calculate received carrier frequency when the mobile is moving in a direction which is 60 degrees to the direction of arrival of the transmitted signal*

Step 7. *In this case,* $\theta = 60^\circ$, $\cos\theta = \cos 60^\circ = 0.5$.

So the Doppler shift is positive.

Step 8. *Doppler frequency or Doppler shift is given by*

$f_d = (f_c / c)\, V_m \cos 60^\circ$

$= (900 \times 10^6 / 3 \times 10^8) \times 20 \times 0.5$

$= 30$ Hz

Step 9. *Hence, the received carrier frequency at the mobile* $= f_c + f_d$

$= 900 \times 10^6 \text{ Hz} + 30$ Hz

$= 900.00003$ MHz

***(d)** To calculate received carrier frequency when the mobile is moving in a direction perpendicular to the direction of arrival of the transmitted signal*

Step 10. *In this case,* $\theta = 90^\circ$, $\cos\theta = \cos 90^\circ = 0$.

So there is no Doppler shift.

Step 11. *The received signal frequency is the same as the transmitted frequency.*

Hence, the received carrier frequency = 900 MHz

6. Explain the following cellular terminologies:
   (a)Cell
   (b)Footprint
   (c)Cell cluster
   (d)Cluster size and system capacity.

   Ans:
   (a,b) Cell and footprint

   A cell is the basic geographic unit of a cellular system. A cell is the radio area covered by a cell-site that is located at its centre. In other words, the radio coverage by one base station or a cell-site is referred to as a cell, which is also called a footprint. In a cellular system, the most important factor is the size and shape of a cell. Because of constraints imposed by natural irregular terrain, man-made structures, and nonuniform population densities, the actual shape of the cell may not be either a circle or a regular geometrical shape but may be a little distorted. For proper analysis and evaluation of a cellular system, an appropriate model of a cell shape is needed.

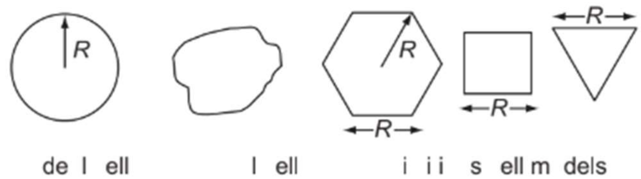


Fig. 4.1 | *Ideal, actual and fictitious cell models*

The actual shape of the cell is determined by the desired received signal level by the mobile subscribers from its base-station transmitter in its operating area. The received signal is affected by many factors including reflections, refractions, and contour of the terrain as well as multipath propagation due to presence of natural and man-made structures.

©Cell cluster

A group of cells that use a different set of frequencies in each cell is called a cellular cluster. Thus, a cluster is a group of cells with no reuse of channels within it. It is worth mentioning here that only a selected number of cells can form a cluster. It follows certain rules before any cell can be repeated at a different location. Two or more different cells can use the same set of frequencies or channels if these cells are separated in space such that the interference between cells at any given frequency is at an acceptable level. That means, the cluster can be repeated any number of times in a systematic manner in order to cover the designated large geographical service area. Let there be K number of cells having a different set of frequencies in a cluster. Then K is termed as the cluster size in terms of the number of cells within it.

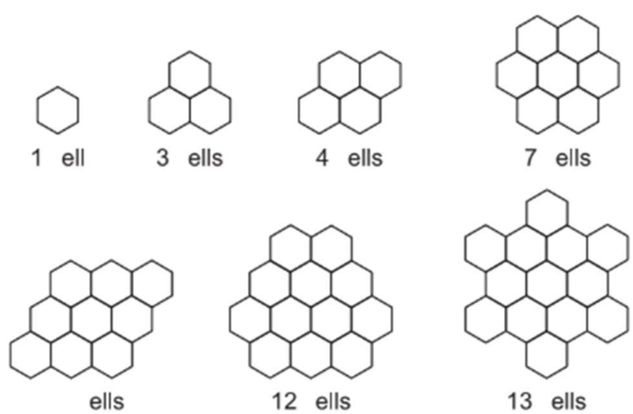


Fig. 4.5 | *Common reuse patterns of hexagonal cell clusters*

(d)Cluster size and system capacity.

The K number of cells in the cluster would utilise all N available channels. In this way, each cell in the cluster contains N/K number of channels only Alternately, the total number of channels available in a cluster, N is equal to the number of channels per cell ($J \le N$) multiplied by the number of cells per cluster (K), that is, $N = J \times K$
In a cellular system, the whole geographical area where the cellular services are required to be provided is divided into a number of clusters having a finite number of cells.

The overall system capacity, C, can then be theoretically determined by simply multiplying the number of clusters in a system (say M) with total number of channels allocated to a cluster, N, i.e.,

$C = M \times N$

Using the relationship $N = J \times K$, we get $C = M \times J \times K$