First Generation Cellular

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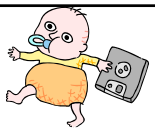
Slides 5

http://www.sis.pitt.edu/~dtipper/tipper.html



First Generation Systems

- Goal: Provide basic voice service to mobile users over large area
- 1 G Systems developed late 70's early 80's, deployed in 80's
  - Advanced Mobile Phone System (AMPS) - USA
  - Total Access Communications Systems (TACS) - UK
  - Nordic Mobile Telephone (NMT) System – Scandanavian PTTs
  - C450 - W. Germany
  - NTT System - Nippon Telephone & Telegraph (NTT) – Japan
- Incompatible systems using different frequencies!
  - Have similar characteristics though

First Generation Systems

- Characteristics of 1G systems
  - Use Cellular Concept to provide service to a geographic area (i.e. number of small adjacent cells to provide coverage)
    - Frequency Reuse
    - Handoff/Handover
  - FDMA/FDD systems
  - Common Air Interface (CAI) standards only
    - Analog Voice communications using FM
    - Digital Control channels for signalling
  - Adjustable Mobile Power levels
  - Macro Cells : 1-40 km radius
- Focus on AMPS system

AMPS

- Advanced Mobile Phone System is first generation wireless in US
  - Earlier systems used line of sight radio (eg, AT&T's Improved Mobile Telephone Service in 1960s)
  - AT&T developed cellular concept in 1940s
  - 1971 proposed High Capacity Mobile Phone Service to FCC
  - 1979 FCC standardized it as AMPS in 800-900 MHz range
  - 1983 launched in Chicago
- Licenses for geographic service areas (similar to radio station model) – areas based on commercial trading zones
  - MSA: metro service area, RSA: rural service area

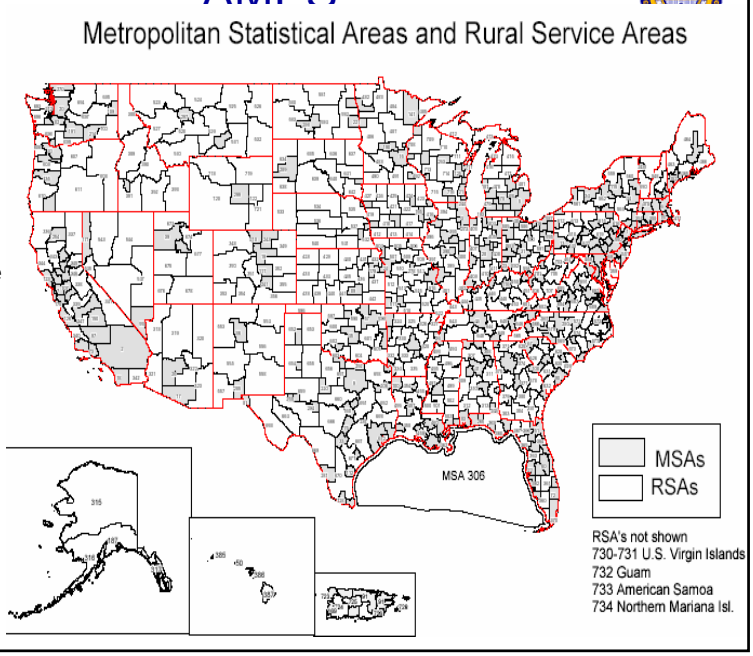
AMPS

FCC allocated 2 licenses for each MSA,RSA

One license to local phone company: wireline common carrier (WCC)

Other license given out by lottery: radio common carrier (RCC)

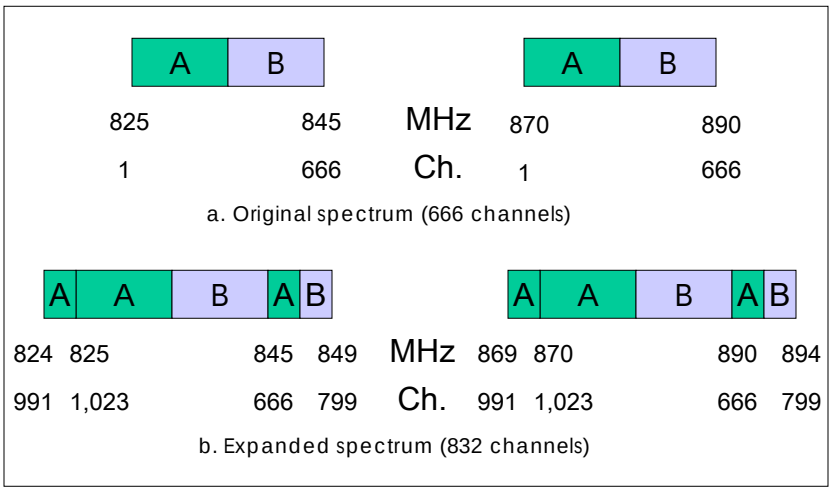
Speculation and fraud in RCC lottery!



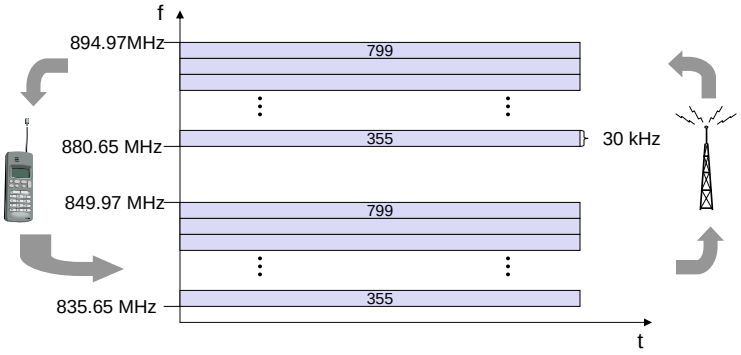
AMPS

- Originally 40 MHz of spectrum separated into two bands of 20 MHz each (A and B band). Later expanded to 25 MHz each
  - A band lower spectrum went to RCC, B band to WCC
- FDD used with 45 MHz separation in uplink and downlink – prevents self interference.
- AMPS uses 30 kHz radio channels between mobile station and base stations (EIA/TIA-533 radio interface)
- Two service providers in area are each allocated 25 MHZ => 12.5 MHz for each direction => 416 pairs of channels: split into 395 voice channels + 21 control channels for signaling
- Channels numbered consecutively 1-666 , when expanded kept same numbering assuming 30 KHz channels even in places were no spectrum allowed
- $f(c)_{uplink} = 825{,}000 + 30 \times (c)$ KHz $\quad 1 \leq c \leq 799$
- $f(c)_{uplink} = 825{,}000 + 30 \times (c-1023)$ KHz $\quad 991 \leq c \leq 1023$
- $f(c)_{downlink} = f(c)_{uplink} + 45{,}000$ KHz

AMPS Frequency Allocation and Channels



FDD/FDMA - AMPS (B block)



$f(c)_{uplink} = 825{,}000 + 30 \times (\text{channel number})$ KHz

$f(c)_{downlink} = f(c)_{uplink} + 45{,}000$ KHz

Initial AMPS System Operators

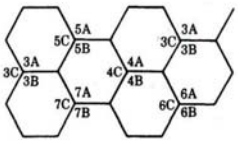
Market No.	Area	System Operator	No. of Cells	Switching Equipment
1	New York	W (B-Side) -Nynex Mobile (6/15/84) NW-Metro One (A-Side) (4/5/86)	56 36	AT&T Motorola
2	LA	W-PacTel Cellular (6/13/84) NW-LA Cellular (3/27/87)	81 38	AT&T Ericsson
3	Chicago	W-Ameritech Mobile (10/13/83) NW-Cellular One (1/3/85)	73 31	AT&T Ericsson
4	Philadelphia	W-Bell Atlantic Mobile (7/12/84) NW-Metrophone (2/12/86)	38 32	AT&T Motorola
5	Detroit	W-Ameritech Mobile (9/21/84) NW-Cellular One (7/30/85)	37 31	AT&T Ericsson
6	Boston	W-Nynex Mobile (1/1/85) NW-Cellular One (1/1/85)	30 10	AT&T Motorola
7	San Francisco	W-GTE Mobilnet (4/2/85) NW-Cellular One (9/26/86)	28 36	Motorola Ericsson
8	Washington	W-Bell Atlantic Mobile (4/2/84) NW-Cellular One (12/16/83)	46 34	AT&T Motorola
9	Dallas	W-SW Bell Mobile (7/31/84) NW-MetroCel (3/1/86)	41 28	AT&T Motorola

Sectored Frequency Planning

- AMPS operators typically used either clusters of size 21 with no sectoring or clusters of 7 in cell frequency reuse pattern with 3 sectors per cell
- Use a Frequency Chart to plan cells: groups frequencies into 21 categories Cells 1-7 and sectors A,B,C in each cell

Block B

1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C
334	**335**	**336**	**337**	**338**	**339**	**340**	**341**	**342**	**343**	**344**	**345**	**346**	**347**	**348**	**349**	**350**	**351**	**352**	**353**	**354**
355	356	357	358	359	360	361														375
376	377	378	379	380	381	382														396
397	398	399	400	401	402	403														417
418	419	420	421	422	423	424														438
439	440	441	442	443	444	445														459
460	461	462	463	464	465	466														480
481	482	483	484	485	486	487														501
502	503	504	505	506	507	508														522
523	524	525	526	527	528	529														543
544	545	546	547	548	549	550														564
565	566	567	568	569	570	571														585
586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606
607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627
628	628	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648
649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	717	718	719
720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740
741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761
762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782
783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799				



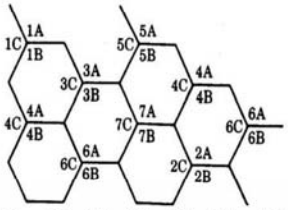
*Boldface numbers indicate 21 control channels for Block A and Block B respectively.

Sectored Frequency Planning

Notice 21 control channels for each provider in center of AMPS band
A provider has 312-333, B provider has 334 – 354

TABLE 3.1 New Frequency Management (Full Spectrum) Block A

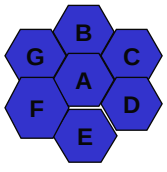
1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
85	86	87	88	89	90												102	103	104	105
106	107	108	109	110	111												123	124	125	126
127	128	129	130	131	132												144	145	146	147
148	149	150	151	152	153												165	166	167	168
169	170	171	172	173	174												186	187	199	190
190	191	192	193	194	195												207	208	209	210
211	212	213	214	215	216												228	229	230	231
232	233	234	235	236	237												249	250	251	252
253	254	255	256	257	258												270	271	272	273
274	275	276	277	278	279												291	292	293	294
295	296	297	298	299	300												312	X	X	X
313*	**314**	**315**	**316**	**317**	**318**	**319**	**320**	**321**	**322**	**323**	**324**	**325**	**326**	**327**	**328**	**329**	**330**	**331**	**332**	**333**
667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687
688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708
709	710	711	712	713	714	715	716	X	991	992	993	994	995	996	997	998	999	1000	1001	1002
1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023



Cell Design - Reuse Pattern

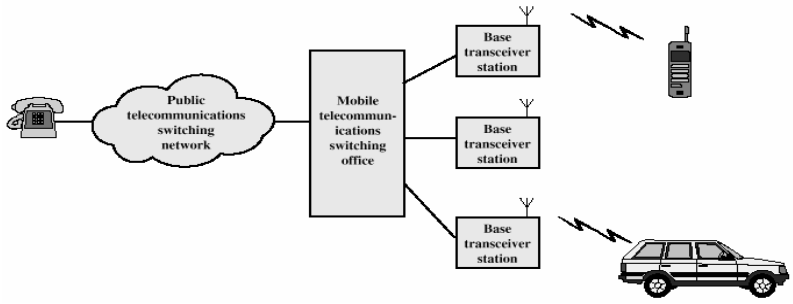
- AMPS equipment usually requires C/I = 18 dB => frequency reuse cluster size K= 21 or K = 7 (usually having 3 sectors per cell).
- For K=7 case and 395 traffic channels have 4 cells in a cluster with 56 channels, 3 cell with 57.
- Traffic load in Erlangs

Cell	Channels	Erlangs (2% blocking)
A	56	47.7
B	56	47.7
C	56	47.7
D	56	47.7
E	57	48.7
F	57	48.7
G	57	48.7



First Generation Systems

- Basic Architecture AMPS, NMT, etc. similar
- Mobile telephone switching office (MisTO) connects base stations to PSTN, location and equipment databases were local to each geographical service area



AMPS (cont)

- Identification numbers:
  - Mobile station's *32-bit binary ESN (electronic serial number)* stored in ROM at time of manufacture
    - 8-bit manufacturer code + 6-bit reserved (unused) + 18-bit manufacturer assigned serial number
  - Service provider's *15-bit binary SID (system identification number)* assigned by FCC license – one for each service provider in an area
    - Transmitted to identify service provider's system
  - Mobile station's *34-bit MIN (mobile identification number)* = 10-digit telephone number
  - *Station Class Mark (SCM):* type of mobile, e.g., 1 – vehicle mount, 4 handheld
  - *Supervisory Auditory Tone (SAT);* tone to identify base station assigned to a call: pure tone at 5970, 6000, or 6030 Hz. Transmitted by both mobile and base station to distinguishes between frequency reuse clusters
  - *Signaling Tone (ST):* 10 KHz tone for on/off hook signalling

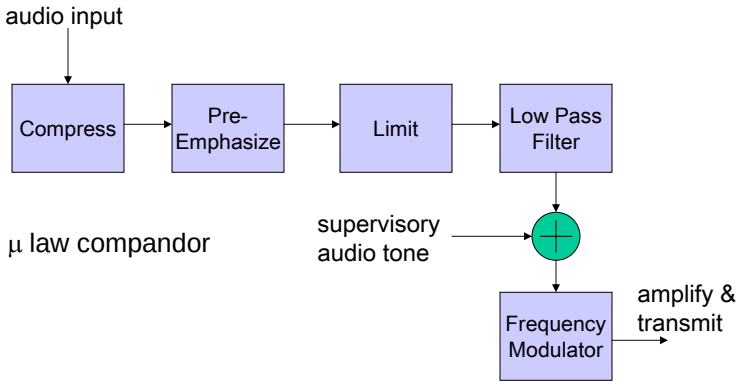
AMPS System Identifiers

Notation	Name	Size (bits)	Description
MIN	Mobile Identifier	34	Directory number assigned by operating company to a subscriber
ESN	Electronic serial number	32	Assigned by manufacturer to a mobile station
SID	System identifier	15	Assigned by regulators to a geographical service area
SCC	Station class mark	4	Indicates capabilities of a mobile station
SAT	Supervisory audio tone	One of three sine wave signals	Assigned by operating company to each base station
DCC	Digital color code	2	Assigned by operating company to each base station

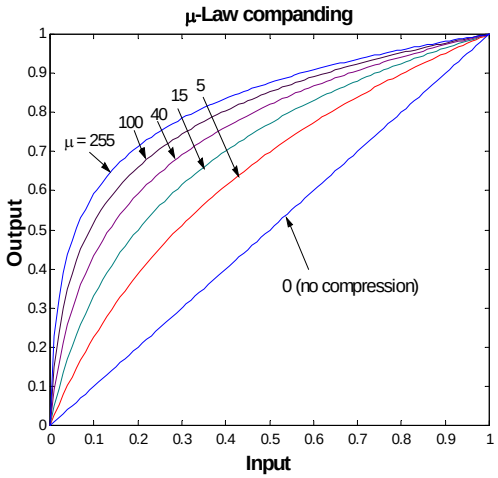
AMPS Logical Channels

Name	Notation	Use	Topology
Reverse Control Channel (1 per sector per cell)	RECC	Signalling	(Random Access) Many-to-one
Reverse Voice Channel (Associated Control Channel)	RVC	Traffic (Signalling)	Dedicated One-to-One
Forward Control Channel	FOCC	Signalling	Broadcast One –to-Many
Forward Voice Channel (Associated Control Channel)	FVC	Traffic (Signalling)	Dedicated One-to-One

AMPS FM modulator



Companding



Analog Compander emphasizes small values, de-emphasizes large values
Reverse the mapping at the receiver with an expandor

$$F(s) = \mathrm{sgn}(s)\frac{\ln(1+\mu|s|)}{\ln(1+\mu)}$$

Modulation Techniques

- Frequency Modulation for voice: change frequency with information s(t)

  $m(t) = V\cos(\varphi(t))$ where

  $d\varphi(t)/dt = \omega + \kappa\, s(t)$

  Bandwidth of FM signal is approximately = 2(MI +1) fmax

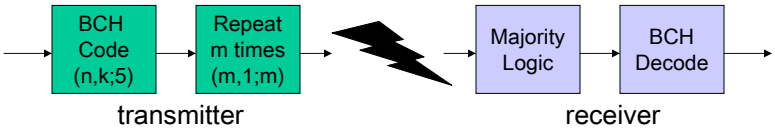
  = 2(3+1)4 KHz = 32 KHz

- For digital control info use same modulator in Frequency Shift Keying (FSK) mode:
  - change frequency with each symbol
  - Manchester format for digital data feed to modulator
  - 10 Kbps channel rate

Channel Coding in AMPS

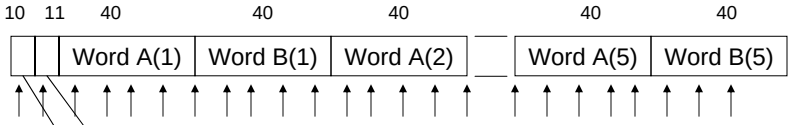
(n channel bits, k information bits; d_{min} minimum distance)

Code rate r = k/n



Channel	n	k	m	b/s
RVC	48	36	5	662-703
FVC	40	28	11	271
RECC	48	36	5	1,250-1,442
FOCC	40	28	5	1,215

AMPS FOCC: Structure



Word sync 11100010010

Bit sync 1010101010 indicator

indicates 1 bit busy/idle status of RECC

Word A(1), wordA(2)… wordA(5) are identical with 28 bits information in a (40,28;5) BCH code

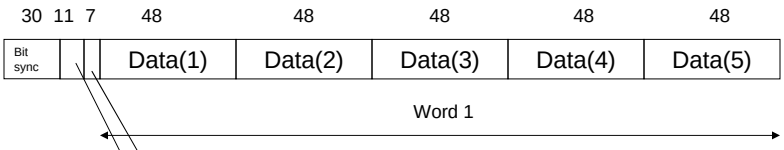
Word B(i) has same format as Word A(i)

Word A bit rate = 28/463 X 10kbps = 604.75 bps

(463=(40x10)+10+11+42 busy/idle bits))

Word(A)
Info for mobiles
With even MIN
Word(B)
Info for mobiles
With odd MIN

AMPS: RECC Structure



Digital Color Code

Word sync 11100010010

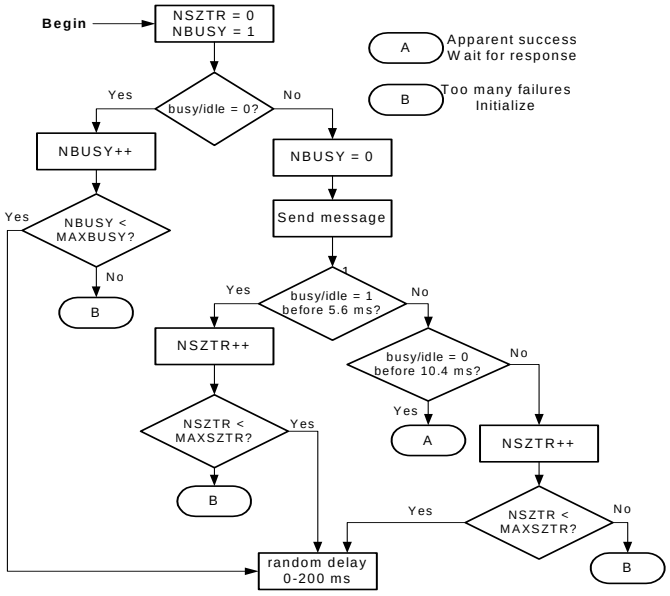
Bit sync 101010…

Data(1)…Data(5) are identical with 36 information bits encoded with BCH (48,36;5) block code

With 1 word per frame 5X48 + 30 + 11 + 7 = 288 bits => data rate = 36/288 X 10kbps = 1250bps

With 5 words per frame = 1248 bits => data rate = 5 x 36/1,248 x 10Kbps = 1442 bps

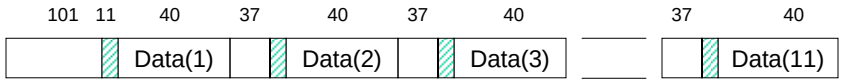
Reverse control channel access protocol



AMPS - Initialization

Base station		Mobile station
		Power up and tune to provider A or B
Control channels	→	Scan and tune to strongest control channel
System parameter message	→	Update operating parameters and SID
Receive MIN, ESN, SID; registers user	←	Control message
Control message	→	Verify initialization parameters; idle state

Associated Signalling FVC: Structure



Word sync 11 bits 1110001010

Bit sync 101010…

Data(1)…Data(11) identical with BCH (40,28;5) block code

Bit rate=28/1032 X 10kbps = 271bps

Permits signalling while a call is in progress

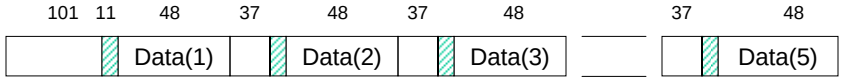
Uses Blank and Burst mode – interrupts voice and replaces it with control information

For example increase/decrease power level of mobile.

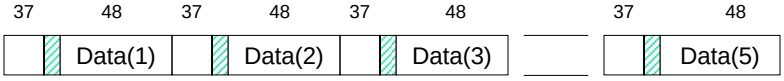
Handoff order

Associated Signalling RVC Structure

Word 1



Word 2



Word sync 11 bits 1110001010

Bit sync 101010…

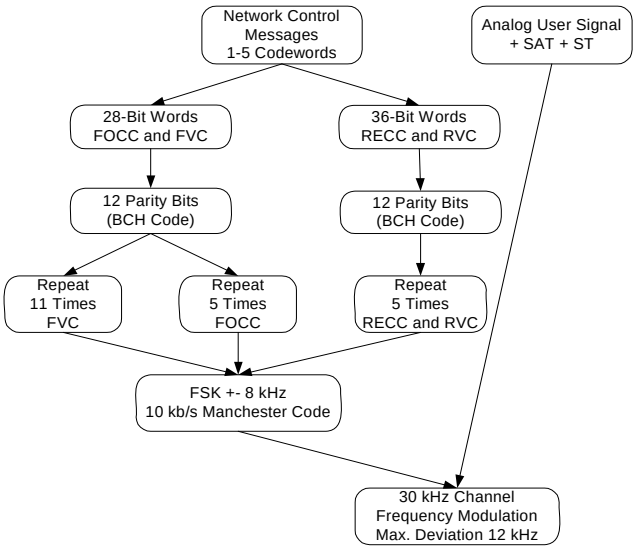
Data(1)…Data(11) identical with BCH (40,36;5) block code

One per frame: 544 bits, with 2 per frame 1024 bits

As in FVC works in Blank and Burst mode

Effective bit rate is 662b/s or 703b/s at 10 Kbps channel speed.

AMPS Transmission Formatting



AMPS Messages

Message	Network Operations
Forward Control Channel Messages	
SYSTEM PARAMETER	Call/Radio Resources Management
GLOBAL ACTION	Radio Resources Management
REGISTRATION IDENT	Mobility Management
CONTROL-FILLER	Radio Resources Management
PAGE	Call Management
INITIAL VOICE CHANNEL	Radio Resources Management
REORDER	Call Management
INTERCEPT	Call Management
SEND CALLED-ADDRESS	Call Management
DIRECTED RETRY	Radio Resources Management
RELEASE	Call Management
CONFIRM REGISTRATION	Mobility Management

AMPS Messages

Message	Network Operations
Forward Voice Channel Messages	
ALERT	Call Management
STOP ALERT	Call Management
MAINTENANCE	Operations admin. and maintenance
RELEASE	Call Management
SEND CALLED-ADDRESS	Call Management
HANDOFF	Radio Resources Management
CHANGE POWER LEVEL	Radio Resources Management

Sample AMPS Messages

HANDOFF message on FVC

Bit Position	Information
1-2	10 a preamble indicates start of message
3-4	SAT of new channel (00, 01 or 10)
5-6	SAT of present channel (00, 01 or 10)
7-14	Not Used
15-17	Power level of new AMPS frequency channel
18-28	New AMPS channel number

CHANGE POWER LEVEL message on FVC

Bit Position	Information
1-2	10 a preamble indicates start of message
3-4	11 indicates not a handoff message
5-6	SAT of present channel (00, 01 or 10)
7-14	Not Used
15-17	New power level
18-28	01011 indicates power control message

AMPS Messages

Message	Network Operations
Reverse Control Channel Messages	
ORIGINATION	Call Management, Authentication
PAGE RESPONSE	Call Management , Authentication
REGISTRATION	Mobility Management
Reverse Voice Channel Messages	
CALLED-STATION ADDRESS	Call Management
ORDER CONFIRMATION	

AMPS - Mobile Originates Call

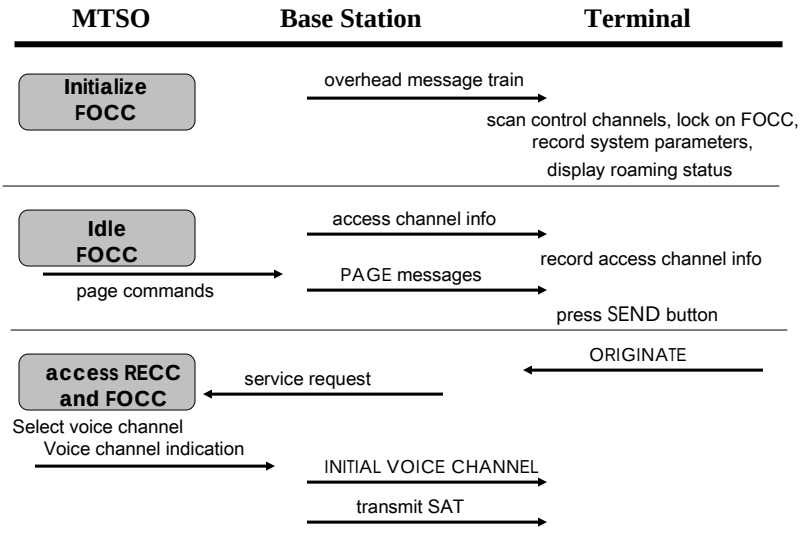
Pass to PSTN ← Origination message (MIN, ESN, called party)

Control message → Tune to voice channel

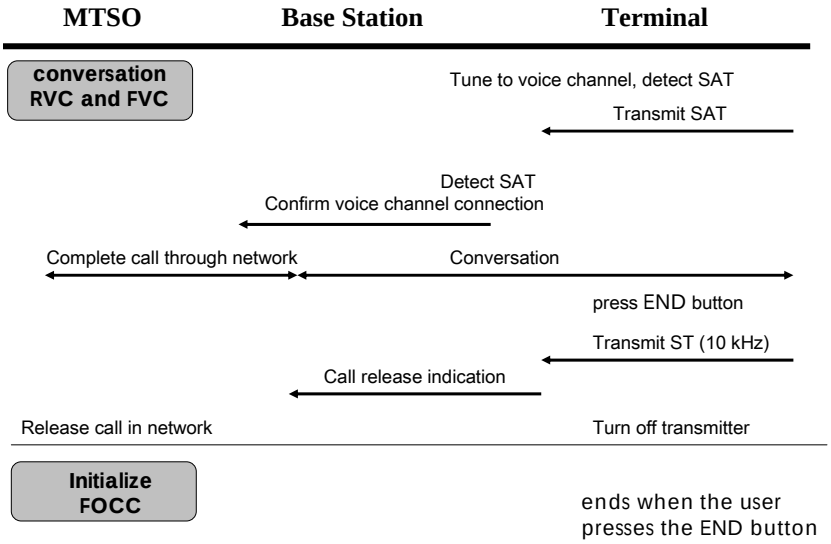
Send supervisory signal to confirm forward channel →

Answers and starts conversation ← Send supervisory signal to confirm reverse channel

AMPS - Mobile Originates Call



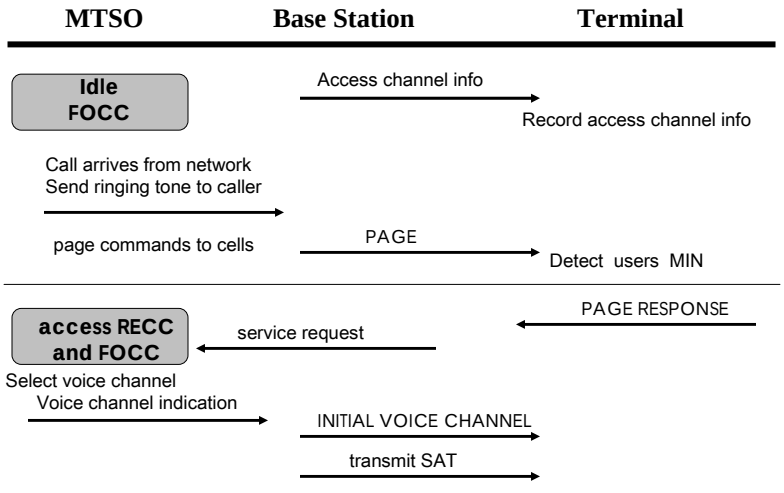
AMPS - Mobile Originates Call continued

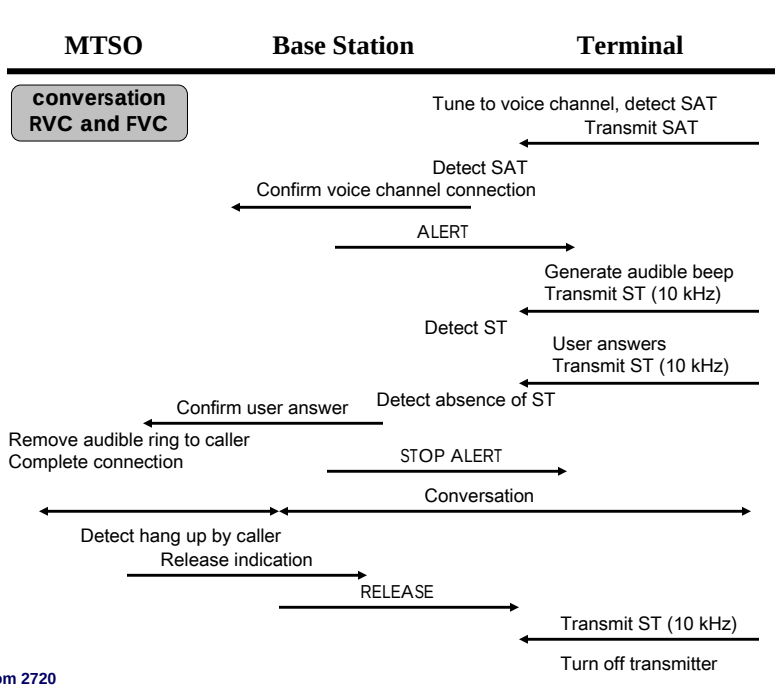


AMPS - Mobile Receives Call

Mobile ID from PSTN; page control message	→	Receives page
	←	Page response message (MIN, ESN)
Control message; tune to voice channel	→	Tune to voice channel
Send supervisory signal to confirm forward channel	↔	Send supervisory signal to confirm reverse channel

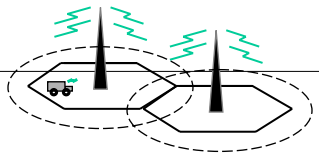
AMPS - Mobile Terminated Call



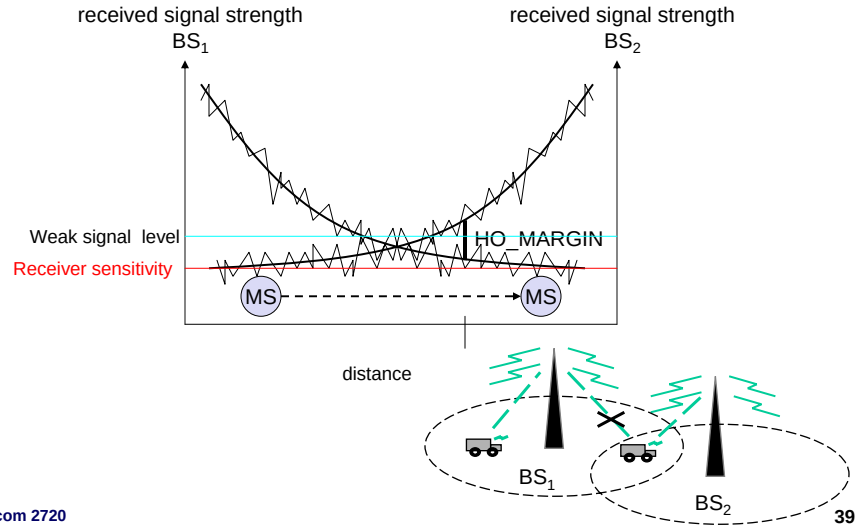


AMPS - Handoff

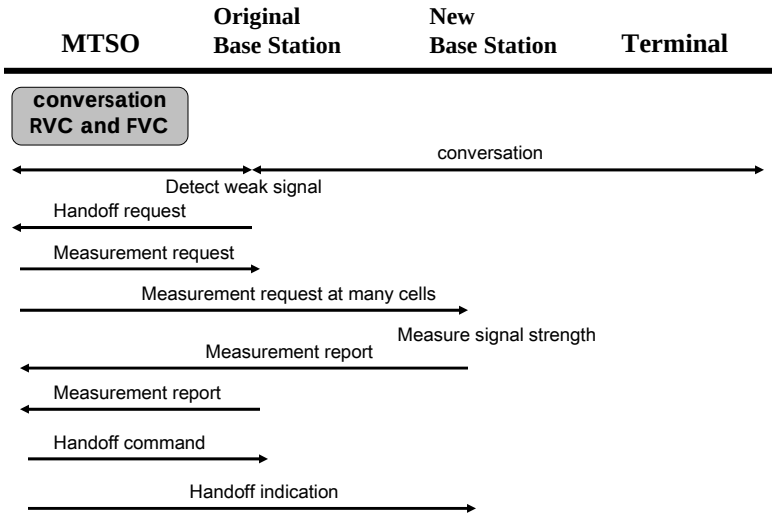
- Handoff initiation:
  - Base station 1 notices mobile station's signal is weakening (when the received signal strength goes below a certain threshold value)
  - Base station 1 sends a handoff measurement request message to its MSC
  - MSC requests neighbor base stations to report their reception of mobile's signal strength
  - MSC pick neighbor base station with highest received signal strength



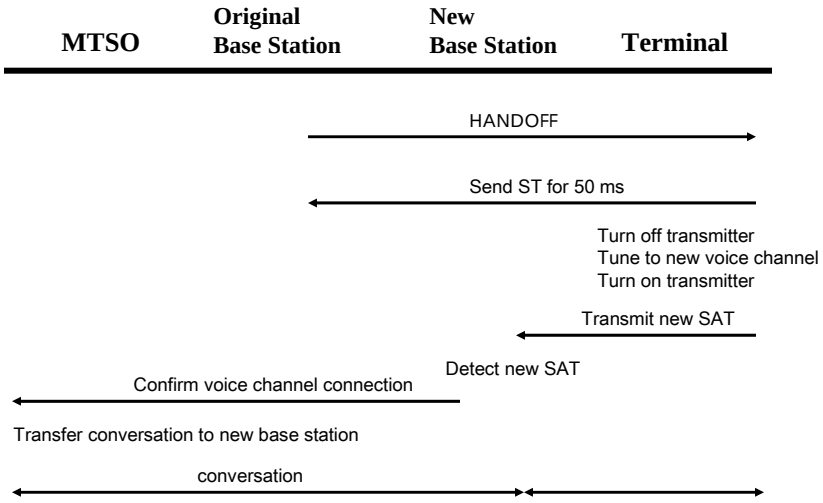
Handoff decision



AMPS Handoff



AMPS - Handoff



Narrowband AMPS

- Motorola developed N-AMPS for low-cost evolution to digital and increase capacity
  - Divided analog channel into 3 by FDMA, decreasing bandwidth 30 kHz per channel to 10 kHz
  - Supported by new 100 b/s in-band sub-audible signaling control channel - also used for text data (paging)
- 1992 Standardized as EIA/TIA IS-88, IS-89, IS-90

First Generation Systems

	U.S. and Canada (AMPS)	U.K. (TACS)	Japan (NTT)	Nordic (NMT450)	Nordic (NMT900)
Number of channels	2 × 416	2 × 500	2 × 500	180	1999
Cell radius (km)	2–20	2–20	2–20	1–40	.5–20
Cell repeat pattern (N)	7, 12	4, 7, 12, 21	9, 12	7, 12	9, 12
Cell receiver frequency (MHz)	825–845	890–915	860–885	453–457.5	890–915
Cell transmitter frequency (MHz)	870–890	935–960	915–940	463–467.5	935–960
Frequency sep. between receiver and transmitter (MHz)	45	45	55	10	45
Channel spacing	30	25	25	25	12.5
Cell-site transmitter power (W)	100	100	25	50	100
Mobile transmitter power (W)	3	7	5	15	6
Voice:					
Modulation	FM	FM	FM	PM	PM
Frequency deviation (kHz)	±12	±9.5	±5	±5	±5
Signalling:					
Modulation	FSK	FSK	FSK	FFSK	FFSK
Formatting	Bi-ø	Bi-ø	Bi-ø	NRZ	NRZ
Frequency deviation (kHz)	±8.0	±6.4	±4.5	±3.5	±3.5
Bit rate (Kbps)	10	8	.3	1.2	1.2

First Generation Systems (cont)

	Japan	North America	England	Scandinavia	Germany
System	NTT	AMPS	TACS	NMT	C450
Transmission Freq: (MHz)					
Base station	870-885	869-894	917-950	463-467.5	461.3-465.74
Mobile station	925-940	824-849	872-905	453-457.5	451.3-455.74
Spacing between Tx and Rx Freq: (MHz)	55	45	45	10	10
Spacing between channels (kHz)	25, 12,5	30	25	25	20
No. channels	600	832 (control ch.21x2)	1320 (control ch.21x2)	180	222

First Generation Systems (cont)

	Japan	North America	England	Scandinavia	Germany
System	NTT	AMPS	TACS	NMT	C450
Coverage radius (km)	5 (urban) 10(suburbs)	2-20	2-20	1.8-40	5-30
Audio signal:					
Modulation			FM		
Frequency deviation(kHz)	±5	±12	±9.5	±5	±4
Control signal:					
Modulation			FSK		
Frequency deviation(kHz)	±4.5	±8	±6.4	±3.5	±2.5
Data Tx. Rate (kb/s)	0.3	10	8	1.2	5.28
Message Protection	Transmitted signal is checked when sent back to the transmitter by the receiver.	Principle of majority decision	Principle of majority decision	Receiving steps pre-determined according to the message content.	Message sent again when an error is detected.

First Generation Systems (cont)

- First generation systems targeted to few subscribers with car phones
  - Rapid growth in demand for cellular services
  - Availability of low cost, lightweight, portable handsets
  - → Growing demand for system capacity
- Capacity can be increased by smaller cells but:
  - More difficult to place base stations at locations for necessary radio coverage
- Increased signaling for handoffs, and more frequent handoffs
  - Base stations handle more access requests and registrations
  - Analog technology has limited options to combat interference effects from smaller cells
- Demand for second generation, digital cellular
  - Also, incompatible first generation (analog) standards in Europe motivated new pan-European digital standard

Generations of mobile communications

Feature/ Decade	1980s	1990s	1999-2002	2002-2010?	2020s
Generation	First	Second	2.5G	Third	Fourth/Fifth
Keywords	Analog	Digital Personal	Wireless Data	High speed wireless data	High Data rate, IP- based, high mobility
Multiaccess	FDMA	TDMA CDMA	**TDMA CDMA**	CDMA	Mixed
Systems	Analog Cellular	Digital Cellular	HSCSD, GPRS,EDGE Cdma 2000	WCDMA, EVDO	4G-Cellular, Hybrid networks
	Analog Cordless	Digital Cordless	Max Data rate 150kbps	Data rate .2-11 Mbps?	Data rate 2-54 Mbps?
		Mobile Data			
		Mobile Satellite			

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