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Advanced Mobile Phone Service:

Mobile Telephone Switching Office

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The Mobile Telephone Switching Office provides centralized control of the Advanced Mobile Phone Service. Using a No. 1/1A Electronic Switching System, the Mobile Telephone Switching Office coordinates and controls the activities of the cell sites, interconnects the mobile telephones with the land telephone network, and maintains system integrity through automated maintenance. This paper gives an overview of the Mobile Telephone Switching Office and addresses the unique call processing and maintenance aspects of mobile telephony.

I. INTRODUCTION

The Advanced Mobile Phone Service (AMPS) provides high-capacity, high-quality mobile telephone service to a large number and variety of customers. The system blends two major communication disciplines: radio transmission and switching. The radio subsystem is based on cellular FM technology[1,2] operating in the 850-MHz band. The switching subsystem is implemented on the No. 1/1A family of the Electronic Switching Systems (ESS).

As described in Ref. 3, the central coordinating element for AMPS is the Mobile Telephone Switching Office (MTSO). It controls the AMPS system and interfaces it with the land telephone network. The MTSO provides mobile customers with services that are similar to those available for land telephones. Basic mobile service includes direct dialed mobile-to-mobile, mobile-to-land, and land-to-mobile calling. An MTSO serves a large geographic coverage area, and all AMPS mobile calls are switched through it.

The AMPS radio equipment is located in remote cell sites.[2] Each cell site also contains duplicated stored program controllers, data link interface equipment, and auxiliary maintenance equipment. Cell sites are connected to the MTSO via voice trunks (referred to as cell-site trunks) and data links.

A high degree of system reliability is attained through automated maintenance. The MTSO controls a number of automated hardware and software maintenance facilities that provide cell-site fault recognition, recovery, and diagnostic capabilities.

II. OVERVIEW OF NO. 1/1A ESS

The No. 1 ESS is described in detail in Ref. 4; the 1A Processor is described in Ref. 5. For completeness, however, an overview of the system is given here. A No. 1 and No. 1A ESS differ in the processor and memory complex.

A No. 1/1A ESS consists of processors, memory, switching network, trunk circuits, and miscellaneous service circuits. This is illustrated in Fig. 1. It is organized as a common control system. Programs that are stored in the switching system's memory provide the logic to control telephone calls. The processors and memory are duplicated for reliability.

The switching network provides a means of interconnecting the lines and trunks. It consists of a matrix of reed switches. Lines from local subscribers terminate on the switching network. Likewise, trunks interconnecting with other switching offices terminate on the network through trunk interface circuits. The reeds are switched under the control of the central processor to produce a metallic voice connection or path between them. The switching network is configured to connect

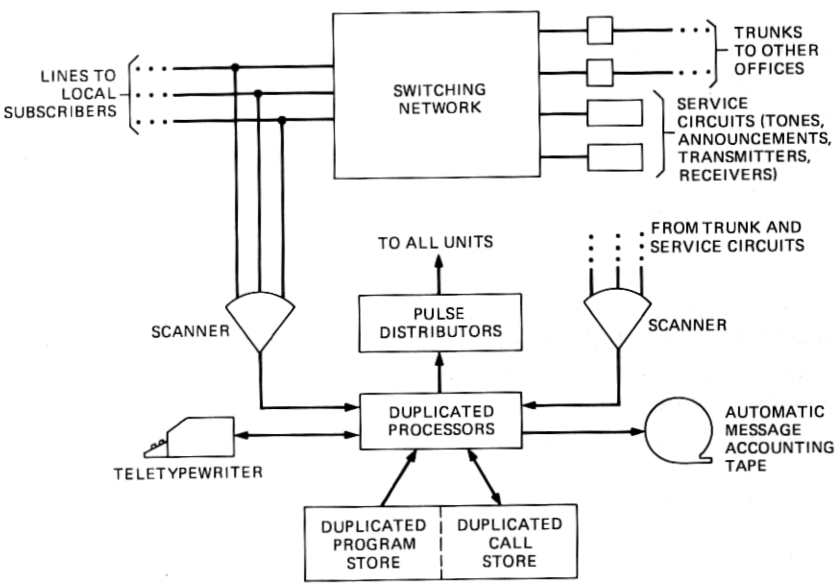

Fig. 1—No. 1/1A ESS block diagram.

any two lines and/or trunks together with an engineered probability of blocking.

As mentioned above, trunks interface to the switching network through trunk circuits which contain interface elements, sensing ferrods for call supervision, and relays to control trunk states for talking, signaling, and testing. A variety of trunk circuits are available, and each application is engineered to meet a particular need, e.g., trunk circuits connected to 2-wire or 4-wire transmission facilities.

The supervisory state of a call is indicated by the presence or absence of a direct-current flow. At least one, and often two, ferrods are employed in every connection (usually in the trunk circuit). Supervisory changes are detected by scanners which are read under the control of the central processor. Stored program control logic then interprets the scanner results. Scanners, then, are the real-time data input devices to the processor.

The central processor controls the switching network and trunk and service circuits by sending orders to them through pulse distributors. The pulse distributors perform an inverse function to the scanners.

Craftpeople interact with the processor through one or more teletypewriters. Through these, the processor prints its output messages and craftpeople input specific commands to the system. Another form of output is the Automatic Message Accounting (AMA) tapes that are used for charge recording data collection. These tape drives only record billing data.

The No. 1/1A ESS operates under the control of its stored program. Three types of programs are resident in the system: call processing, hardware maintenance, and administration. Call processing programs provide the logic that controls call setup and disconnect actions for the wide variety of call types. The maintenance programs provide the means of recognizing hardware failure conditions and reconfiguring the active/standby units to achieve a working system. The maintenance programs also provide diagnosis of suspected failed units to aid in the repair. Administrative programs provide mechanism for changing the system data base. The data base includes customer records, trunk records, billing data, and traffic counts.

An MTSO is built upon standard No. 1/1A ESS hardware. As explained in Section III, the switching operations are all trunk-to-trunk. The logic to control mobile telephone calls and to maintain the cell-site hardware is implemented as an addition to the ESS stored program.

III. MTSO INTERCONNECTION

3.1 MTSO to wire-line network

In the Chicago Equipment Test, the MTSO occupies a position in the switching hierarchy below a class 5, or local, office. This is illustrated in Fig. 2. The MTSO can be interconnected with one or more local offices over standard trunk facilities. Directory numbers for mobile

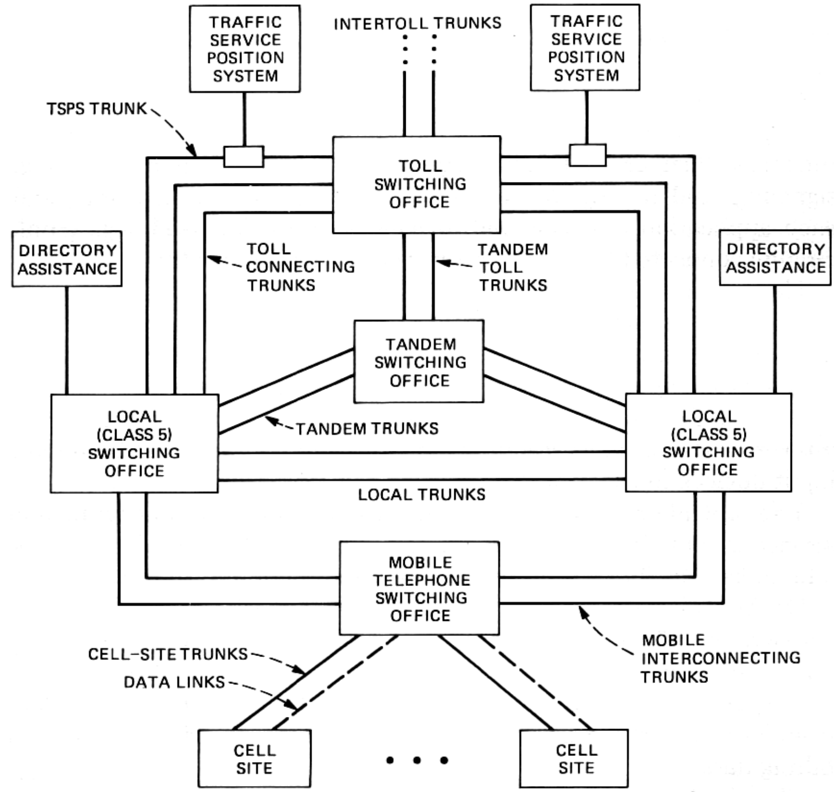

Fig. 2—Position in hierarchy.

telephones are assigned from within the local exchanges that are served by those interconnected offices. The MTSO interconection arrangement is similar to that used with a Private Branch Exchange (PBX), and it makes use of existing capabilities in ESS local offices.

Mobile-originated calls into the land telephone network are outpulsed from the MTSO using *TOUCH-TONE** signaling. Dial-pulse signaling can also be used. The MTSO selects and seizes the outgoing trunk to the local office. It begins outpulsing the called digits after the local office sends a start pulsing, or wink, signal, The wink is a momentary battery reversal on the trunk. Answer and disconnect supervision signals are returned from the local office to the MTSO allowing charging records to be made.

On land-to-mobile calls, the local office outpulses the called mobile's telephone number to the MTSO using either multifrequency, dial pulse, or *TOUCH-TONE* signaling. The MTSO returns answer and disconnect supervision signals back to the local office.

The MTSO routes calls within the AMPS system and into the wire-line network. The simplest call routing is the mobile-to-mobile call. The

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MTSO receives the dialed digits from the calling mobile, determines that the called number is another mobile, and completes the connection to that called mobile. None of the interconnected offices are involved. This case is illustrated in Fig. 3a.

On direct-dialed, mobile-to-land calls, the MTSO routes the call into the land telephone network through one of the local offices. Routing tables stored in the MTSO provide the association between the called number and the proper local office to be used. For standard calls, the directory number of the calling mobile does not influence the routing. Exceptions to this include operator assistance, emergency service, and repair service. The mobile-to-land connection is shown in Fig. 3b.

Land subscribers can directly dial calls to mobiles. Since mobile directory numbers are assigned from those available in local exchanges, there is a correspondence between each mobile and a particular local office. The land telephone network directs calls to the local office serving the exchange of the called number without knowing the call is to a mobile. Upon receiving such a call, the local office connects that call to a direct trunk to the MTSO which, in turn, completes the connection to the mobile. A land-to-mobile connection is identical to that shown in Fig. 3b.

Operator-assisted and service calls (e.g., repair service) can also be dialed from a mobile. The MTSO does not have direct trunks to operator or service bureau positions. Instead, it makes use of those services already available in the local offices. The MTSO routes these calls to a local office which connects the calls to operator and service position trunks. The call routing is shown in Fig. 3c.

3.2 MTSO to cell site

Figure 4 illustrates the interconnection of the MTSO to several cell sites. Two types of facilities are used. First, cell-site trunks provide a voice communication path. The number of trunks is engineered on the basis of traffic and desired blocking probability. Each trunk is physically connected to a cell-site voice radio. The type of trunk is dependent on the overall system transmission plan. This selection determines the appropriate ESS trunk circuit.

A cell site acts in the radio frequency domain as a traffic concentrator for the MTSO. Assuming an average busy-hour mobile unit occupancy of a few percent and a grade-of-service objective comparable with land service, an average busy-hour radio channel occupancy of at least 60 to 70 percent results for higher traffic cells.

The MTSO also connects with the cell sites through two 2400-baud data links operating in a full duplex mode. Figure 4 illustrates the connection of the data link equipment to the ESS and to the cell site. The data link hardware at the MTSO is not unique to AMPS; it is also used in No. 1 ESS Toll Common Channel Interoffice Signaling (CCIS). A Terminal Access Circuit (TAC) provides the interface between the internal ESS buses and the data link terminals (see Fig. 10). The TACS

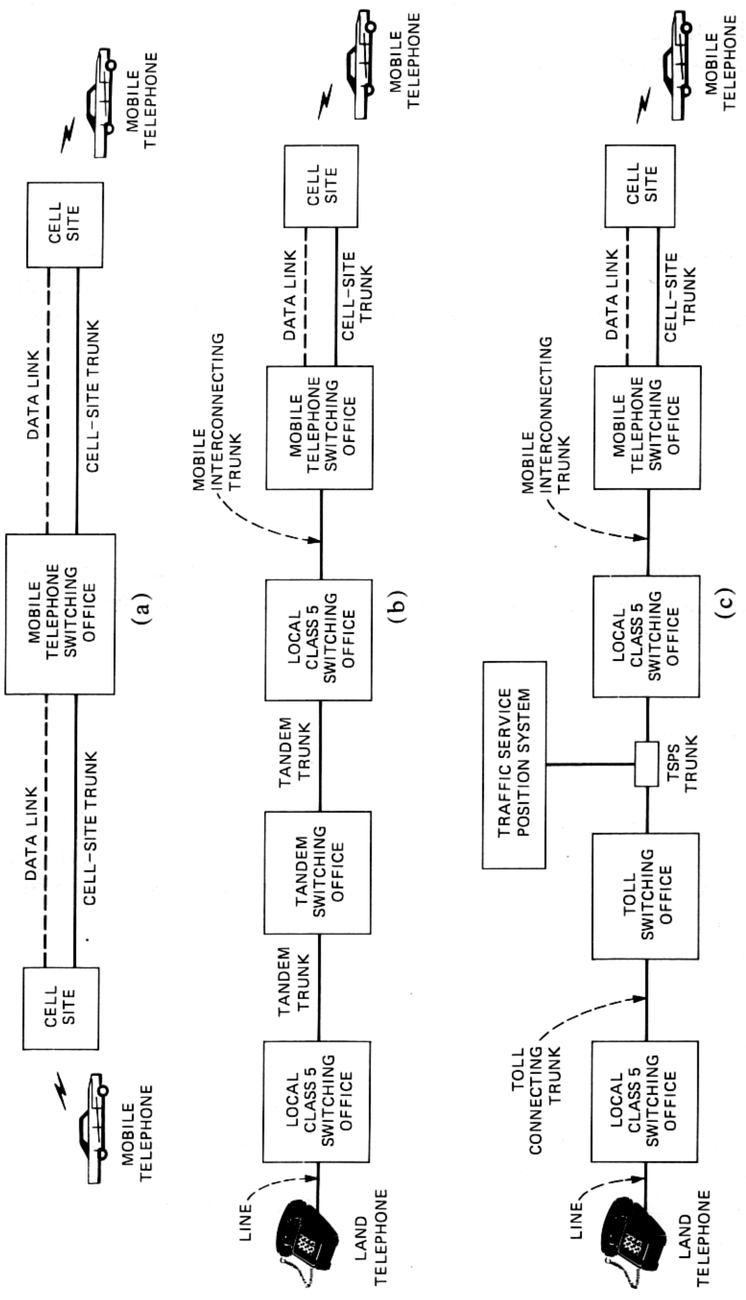


Fig. 3—(a) Mobile-to-mobile call. (b) Typical mobile-to-land call. (c) Typical mobile-originated, operator-assisted call.

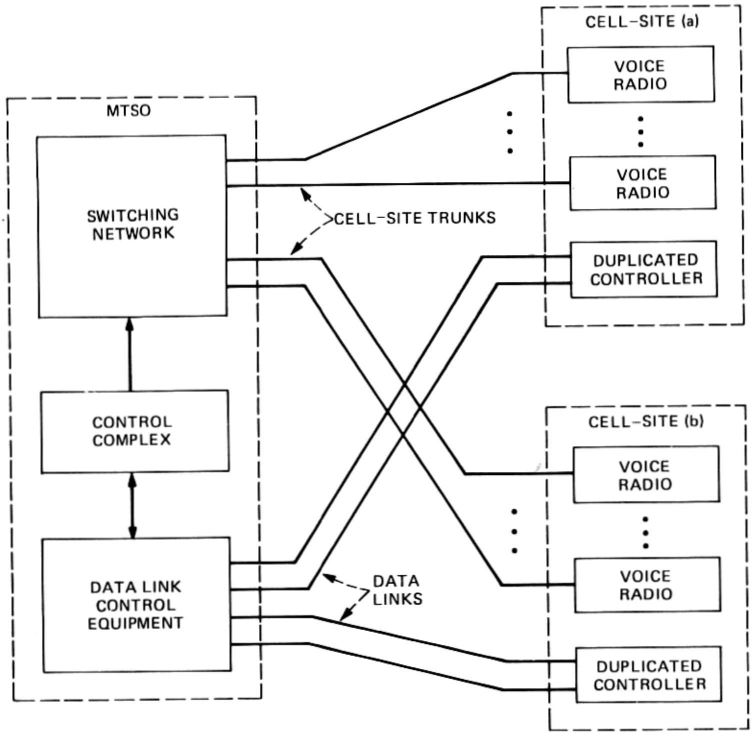


Fig. 4—MTSO—cell-site interconnection.

are duplicated for reliability. A duplicated pair of TACs controls 16 data link terminals, each of which drives two data modems. The data links to each of the cell sites are controlled by different terminals to provide high reliability. In the event of a data link failure, communication can continue between the MTSO and a cell site by reconfiguring either the TAC or terminal, as appropriate.

IV. MTSO CALL PROCESSING

The MTSO is the central controller for processing mobile telephone calls. Reference 3 describes the basic system plan and outlines some representative call sequences. In carrying out these sequences, the MTSO performs a number of functions that differ from a conventional wire-line switch either in the nature of the function itself or in the implementation. Table I illustrates these differences.

The following activities are representative of the MTSO call processing:

(*i*) Providing switched interconnection with the land telephone network.
(*ii*) Providing switched connections between mobile subscribers served by the MTSO.
(*iii*) Administering the usage of the radio voice channels.

Table I—Land switching/mobile switching functional comparison

Function	Local ESS	MTSO
1. Connection	Space division network	Space and distributed frequency division network Path reconfiguration (handoffs)
2. Control	Central control	Central control Remote control (cell sites)
3. Attending (origination)	Scanners	Setup channel location/identification
4. Information receiving and transmitting	Dial pulse *TOUCH-TONE®* Standard interoffice signaling	Preorigination digital dialing *TOUCH-TONE* interoffice signaling
5. Busy testing	Memory function	Memory function
6. Availability testing	Continuity tests	Paging
7. Alerting (ringing)	Subset ringing from CO (90 V, 20 Hz)	Activated in mobile by a digital message from MTSO
8. Supervising (call in progress)	Line scanners	Trunk scanners
9. Monitoring for transmission quality		Location function

(*iv*) Providing control over signaling with the mobile units.

(*v*) Providing control of the intercell location process and the resulting handoffs.

(*vi*) Recording charge information.

(*vii*) Providing custom services to mobile users.

The following examples illustrate the nature of mobile call processing within the MTSO.

4.1 Mobile-originated calls

The MTSO receives a request for a mobile-originated call as a data message from a cell site. Each origination message contains the calling mobile's identification, the complete called number as dialed, and the serving cell-site identification. The MTSO analyzes the called number. If the origination attempt is correct and allowed, the MTSO selects an outgoing trunk. The MTSO may deny an origination attempt from a restricted subscriber. If an attempt is incorrect or incomplete, the MTSO sends a reorder or intercept data message to the subscriber.

For the successful origination attempts, the MTSO selects an idle cell-site trunk (and associated voice radio). The MTSO sends a data message to the cell site serving the mobile, instructing the mobile to tune to the assigned voice frequency. The MTSO then scans the ferrod associated with the cell-site trunk for an on-hook to off-hook state transition which indicates that the mobile did indeed tune to the new channel. If a voice channel assignment confirmation is not received, the MTSO attempts a single retry. The call is terminated if the retry is not confirmed.

For those calls where the voice channel assignment is successful, the MTSO seizes an outgoing trunk to the local office as determined by digit analysis. A transmitter is connected, and the called number is outpulsed. At the completion of outpulsing, the cell-site trunk is connected to the outgoing trunk, thereby establishing a talking path. Figure 5 illustrates the mobile-originated call setup switching process and associated signaling.

On each mobile-originated call, the MTSO makes an AMA entry for charging purposes. Section 5.1 elaborates on the contents of the data entry.

4.2 Mobile-completed calls

On a call to a mobile, the MTSO receives the completion attempt on an incoming trunk. It connects a digit receiver and collects the called digits. The MTSO analyzes the digits and identifies the called mobile if the dialed number is valid. Calls to invalid numbers are routed to an intercept announcement. The MTSO then initiates a paging process to locate the mobile within a particular cell. The MTSO does this by sending a data message to each active cell site. Only one cell site should respond, thereby identifying the called mobile's location. Three possible situations can occur. First, only one cell site responds and the call processing proceeds as described below. Second, no response is received. In this case, the MTSO retries the page process one time. A second no-response condition is taken to mean the mobile is not there,

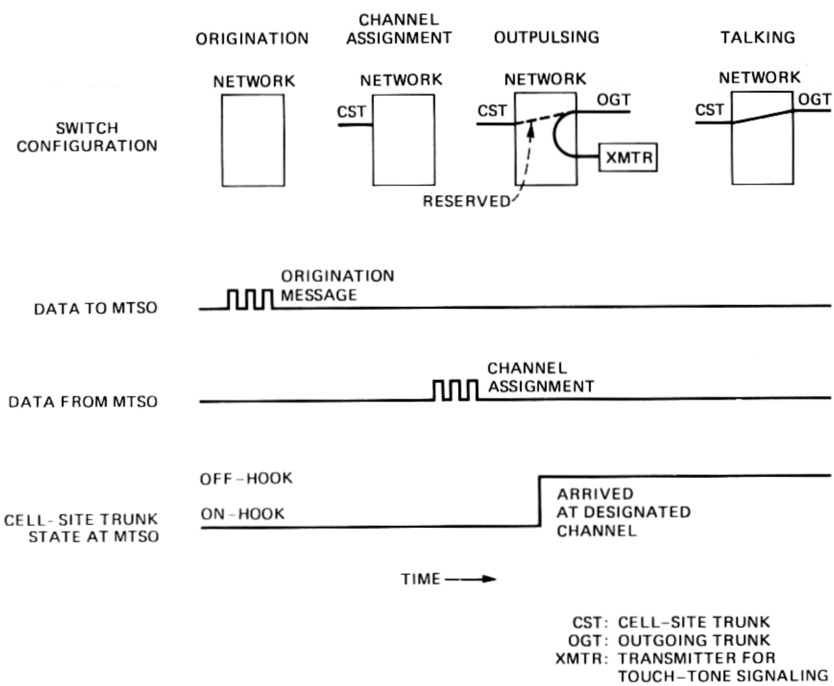


Fig. 5—Mobile-originated call.

and the MTSO connects the calling party to a recorded announcement. Third, more than one response may be received. This is an error condition, and the MTSO attempts to set up the call based on the first response. Subsequent responses are ignored.

For a successful page response, the MTSO directs the mobile to tune to a voice channel in the same manner as described in the previous section. Once the mobile has tuned successfully, the MTSO begins the alerting, or ringing, process. The MTSO alerts the mobile customer by sending a data message which activates an alert facility (ringer) in the mobile unit. The MTSO connects audible ringing tone to the calling party. Confirmation of the mobile's receiving the alert message is seen at the MTSO as an off-hook to on-hook state transition on the cell-site trunk. Next, the MTSO detects the mobile customer answer by scanning for an on-hook to off-hook transition on the cell-site trunk.

When an answer is received, the MTSO removes the audible ringing tone from the incoming trunk. It then connects the incoming trunk with the cell-site trunk, establishing the talking path between the two parties. Figure 6 illustrates the signaling and MTSO switching actions.

4.3 Locating and handoff

Calls in a talking state are supervised for adequate voice channel signal quality by the MTSO through a coordinated effort with the cell

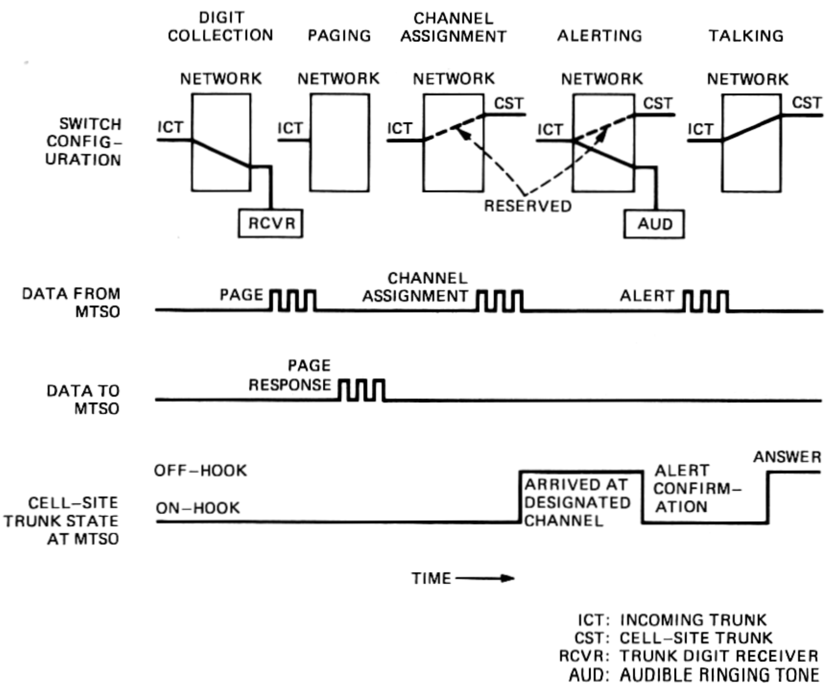


Fig. 6—Mobile-completed call.

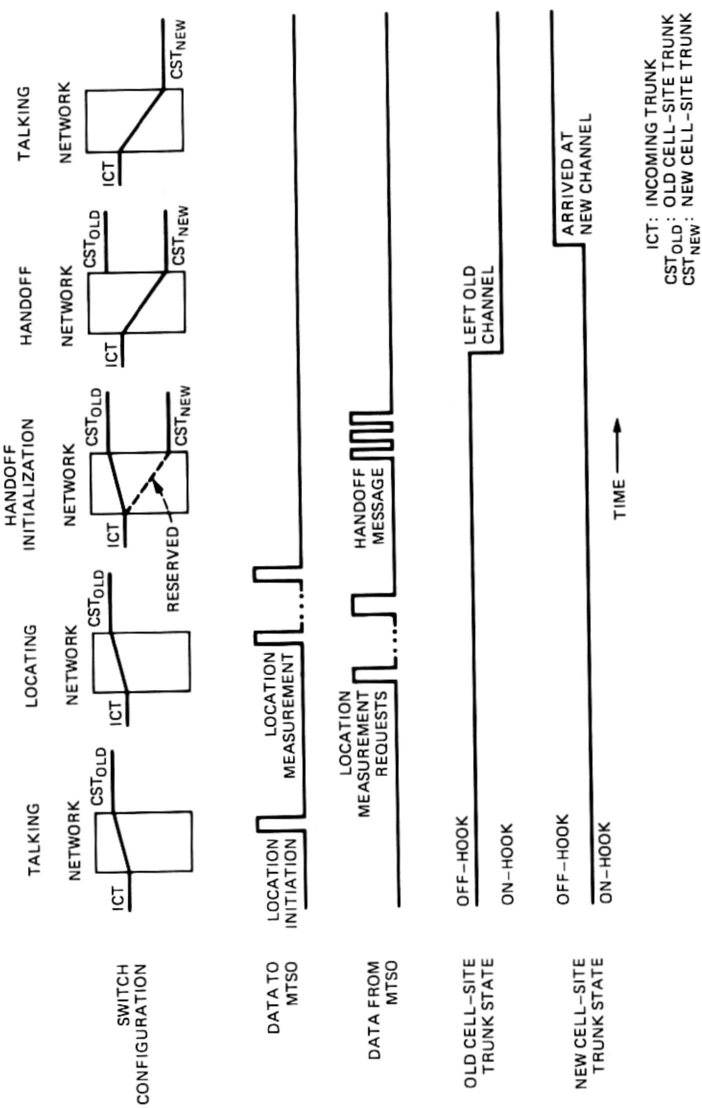


Fig. 7—Handoff.

sites. Under their internal program control, cell sites monitor the received mobile signal quality on all voice channels that are in use. The MTSO collects signal quality information from serving and adjacent cells and determines when a handoff process should be initiated. However, if no cell site can adequately serve the mobile, the MTSO leaves the call undisturbed on the original cell site.

The handoff process involves four operations:

(*i*) Selecting a cell-site trunk to the new serving cell site.

(*ii*) Instructing the mobile to tune from its present voice channel to the one corresponding to the new cell-site trunk.

(*iii*) Setting up a talking path in the switching network from the new cell-site trunk to the incoming or outgoing trunk.

(*iv*) Idling the talking path in the switching network between the old cell-site trunk and the incoming or outgoing trunk.

As shown in Fig. 7, the MTSO uses the states of the cell-site trunks to infer the state of the mobile. After the MTSO sends a data message instructing the mobile to tune, it scans the old cell-site trunk for an off-hook to on-hook transition as a confirmation that the mobile left the old voice channel. The MTSO also scans the new cell-site trunk for the opposite transition as a confirmation that the mobile arrived at the new channel. No AMA record is made for handoffs.

4.4 Disconnect

The MTSO is responsible for controlling the states of all equipment in a speech path. This equipment consists of an incoming or outgoing trunk, a switching network path, a cell-site trunk, a cell-site radio (transmitter-receiver pair), and a mobile unit transceiver. During both normal disconnect and failure actions, the MTSO deals with the radio components in addition to the switching network and trunks.

The MTSO turns on a cell-site transmitter when a voice path is set up and turns it off when a voice path is torn down. Thus, cell-site transmitters radiate power only while their associated channels are in use. The MTSO does this by sending data messages to the cell site.

During a normal disconnect where the land party goes on-hook first, the MTSO instructs the mobile via a data message to tune back to the setup channel. This clears the associated voice channel for the next call and puts the mobile in the correct state to initiate or receive its next call. If the mobile disconnects first, it autonomously retunes to the setup channel, and the MTSO turns off the associated cell-site transmitter by sending a data message.

Several ambiguous situations can occur during disconnect processing where the MTSO does not know the true state of the mobile. An example is when no carrier signal from a cell site is seen by a mobile. Here, the mobile autonomously times for several seconds and retunes to the setup channel. Thus, for some time, a mobile may be on a voice channel in an autonomous timing state during a possible disconnect. The MTSO holds the cell-site trunk associated with such a mobile for a 5- to 6-second guard timing interval. This ensures that the trunk will not be reassigned to a new call before the old mobile leaves the channel.

In addition, mobiles exhibit another characteristic called fading. A mobile may be in a talking situation and drive into a radio path fade due to a poor propagation situation. The MTSO is notified of such an event by the cell site. If the length of a fade exceeds about 5 seconds, the cell site signals this to the MTSO by placing the associated trunk on-hook. The MTSO initiates normal disconnect processing, and it discovers that the disconnect was due to a fade when the cell-site voice transmitter is turned off. The cell site sends a message to the MTSO saying that the call was involved with fade timing. The MTSO records a fade indicator in the AMA record so that billing adjustments can be applied.

4.5 Unsuccessful calls

Calls may be unsuccessful for a variety of reasons including:

(*i*) Dialing errors.
(*ii*) Equipment malfunctions.
(*iii*) Busy conditions.
(*iv*) Traffic blocking.
(*v*) Signaling errors.

The MTSO has a set of informative recorded announcements and tones which are used to provide indications about call failures to the originating party. For example, traffic-busy conditions are indicated by reorder tone.

Tones given to mobile users may come from either the MTSO tone sources or the mobile unit itself. The MTSO controls the application of the tones. For failures encountered after a mobile has successfully tuned to a voice channel, the MTSO connects the cell-site trunk to the appropriate tone source or announcement. If the failure occurs before voice channel assignment, the MTSO sends a data message instructing the mobile unit to activate an internal tone.

V. MTSO ADMINISTRATIVE PROCESSING

5.1 Billing

The MTSO records all charge-related data for the AMPS system on its AMA tape. In contrast to conventional wire-line switching offices, the MTSO records a billing entry for all calls to a mobile as well as those from a mobile. An entry is made on all calls that successfully tune to a radio voice channel.

For mobile-originated calls, the data that are recorded include the conventional called and calling numbers, answer time, and disconnect time. This portion of the record deals with the message unit and toll charges associated with the wire-line network. Also recorded in the AMA entry is the radio voice channel seizure and release times and the initial cell-site identification. These items pertain to the usage of the AMPS radio facilities.

For mobile-completed calls, the office in which the call originated creates a billing record covering the usage of the land telephone network. The MTSO records the radio usage data (the voice channel seizure and release times and initial cell site).

5.2 Service orders

The MTSO translation data base contains the records associated with each mobile customer. Typical data include:

(*i*) Mobile directory number.

(*ii*) Billing classification data.

(*iii*) Custom services subscribed to.

Each time a customer is added or deleted or changes service options, the MTSO data base is updated accordingly. The records associated with this activity are called service orders.

Clerks receive written orders detailing service changes. They input these orders into the MTSO data base via a teletypewriter.

Messages changing the MTSO data base are called recent change messages. They are processed by an extensive set of MTSO programs which check them for format and data errors. Error conditions are flagged back to the clerk on the teletypewriter. Error-free messages cause the appropriate translation data records to be altered.

5.3 Trunk changes

The number of trunks interconnecting the MTSO with each local office and cell site is engineered based on the expected traffic. Given a traffic load and desired blocking probability, the required number of trunks can be determined. As a system grows, the number of trunks changes. Recent change messages are available in the MTSO to add or delete trunk records in the translation data base. Again, administrative programs process these messages for validity and update the data base accordingly.

One unique aspect of trunk changes in AMPS is a correspondence between a cell-site trunk and a radio voice frequency. The translation data in the MTSO memory associate a cell-site trunk with a specific frequency. When voice-channel frequencies are changed at a cell site, the corresponding trunk translations are altered with recent change messages.

5.4 Traffic measurements

As previously mentioned, the amount of traffic the system carries determines the amount of equipment in the MTSO. The MTSO collects traffic data on call attempts and equipment usage to aid office engineering. The traffic-engineered items include:

(*i*) Number of trunks.

(*ii*) Number of service circuits.

(*iii*) Amount of memory.

(*iv*) Amount of switching networks.

(*v*) Number of data links.
(*vi*) Number of cell sites.

Generally, three counts are maintained on each traffic-engineered component. These counts are total seizure attempts, total blocked attempts, and usage. Seizure attempts and blocked attempts are self-explanatory peg counts. Usage counts are taken at 10 or 100-second intervals. The usage counts indicate how many pieces of equipment in the group are busy at the sample time. The traffic measurements are summarized and printed on the MTSO teletypewriter at various times of the day.

VI. AMPS SYSTEM MAINTENANCE

6.1 System maintenance concepts

The measure of the success of a commercial venture is directly related to customer satisfaction and economic considerations. Telephone customers gauge their satisfaction by low-cost, continuous, accurate service with minimal service delay and/or interruption. System availability is defined as a measure of service continuity and accuracy, while maintainability can be defined as the ease with which failures can be detected, isolated, and corrected.[4]

Common measures of functional system reliability include the following measures, which are graphically illustrated in Fig. 8:

$$A = \text{Availability} = \frac{\text{MUT}}{\text{MTBF}} = \frac{\text{MEAN-UP-TIME}}{\text{MEAN-TIME-BETWEEN-FAILURES}}$$

$$A = 1 - \frac{\text{MEAN-RECOVERY-TIME (MRT)}}{\text{MTBF}}$$

$$DT = \text{Total Down Time Over System Life(T)} = (1 - \text{A})\text{T}.$$

While the overall AMPS system objectives are comparable to those for the No. 1 ESS central office, the downtime objectives for a single cell site are somewhat less stringent. This is in part due to the geographic redundancy afforded by the cellular concept. Mobile coverage, albeit sometimes degraded, can be adequately provided by neighboring cells in the mature system.

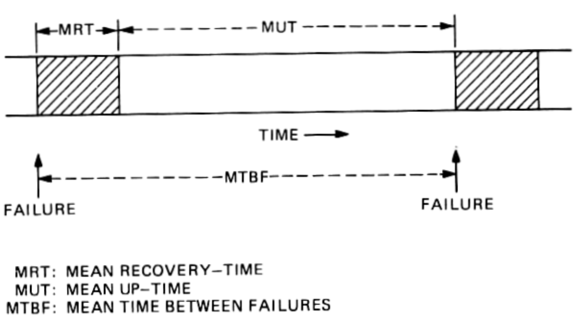


Fig. 8—Equipment availability.

To increase the MTBF of a system, the design must

(*i*) Reduce component count.
(*ii*) Increase component reliability.
(*iii*) Make the system immune to human error.

However, in practice, the aforementioned items may be difficult to achieve. Equivalently, one can increase the availability of the system by reducing the overall system MRT. This can be accomplished by

(*i*) Duplicating critical units.
(*ii*) Providing good interconnection and automatic switching.
(*iii*) Detecting faults rapidly.
(*iv*) Providing automatic fault isolation.
(*v*) Providing automatic fault location.

6.2 No. 1/1A ESS system maintenance

Maintenance of the 1/1A ESS system is described in Ref. 3. System maintenance emphasizes reductions in the MRT. This is accomplished by employing the following hardware techniques:

(*i*) Duplication.
(*ii*) Enabling codes and operation verification.
(*iii*) Parity and bit corrections.
(*iv*) Matched synchronized units.
(*v*) Automatic quarantine.
(*vi*) Hardcopy memory backup.
(*vii*) Control access to stores and peripheral.
(*viii*) Roving spares.

The maintenance program has three distinct functions:

(*i*) Fault recognition and error recovery to restore the system to an operational state and isolate faulty hardware.
(*ii*) Diagnose suspected faulty units and provide fault sectionalization and isolation.
(*iii*) Routine exercises to supplement error recovery, fault sectionalization, and early detection of transient problems.

Many of the duplication and maintenance philosophies adopted in No. 1/1A ESS have been adapted to the AMPS cell maintenance software.

Figure 9 is a broad overview of the processing of fault condition within the No. 1/1A ESS.

6.3 Data link terminal access circuit and data terminal maintenance

The Data Terminal frame consists of two types of reconfigurable hardware units. These are the standard data terminal (DTRM) and the terminal access circuit (TAC). The DTRM is an autonomous controller for either one or two data links. Its primary function is to bidirectionally buffer and format data link messages. The DTRM contains a stored program controller which can be updated by the No. 1/1A Processor. The TAC interfaces the No. 1 ESS peripheral system with up to a

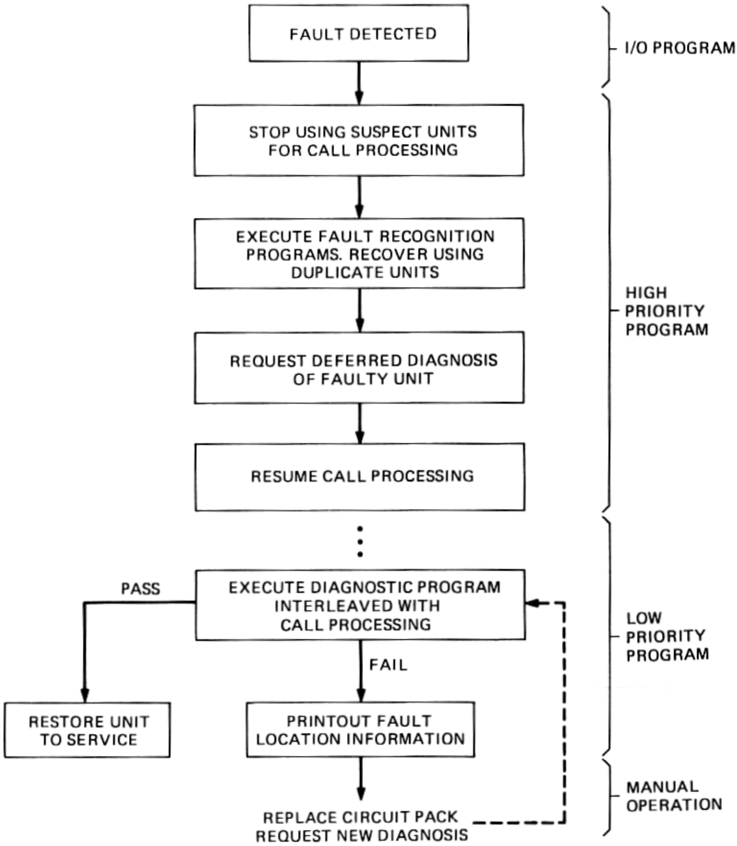


Fig. 9—Reaction to ESS trouble.

maximum of 16 DTRMS. The cell site interconnection is shown in Fig. 10.

When a No. 1/1A Processor executes a peripheral order, several self-checking circuits are activated as part of the I/O process. If one or more of these self-checks fail, an F-level interrupt is generated in the processor, and the F-level recovery programs are immediately given control. Since F-level interrupts are only generated during the execution of peripheral orders, the DTRM cannot always cause an interrupt when the fault occurs. Instead, trouble indicators are buffered in the TAC until a peripheral order is executed. Thus, certain interrupt inducing failures cannot be directly associated with the particular failing orders.

6.3.1 F-Level recovery programs

After a failure of a peripheral operation, the primary function of the F-level recovery programs is to configure a working peripheral system. Two basic techniques are used to isolate troubles in the peripheral

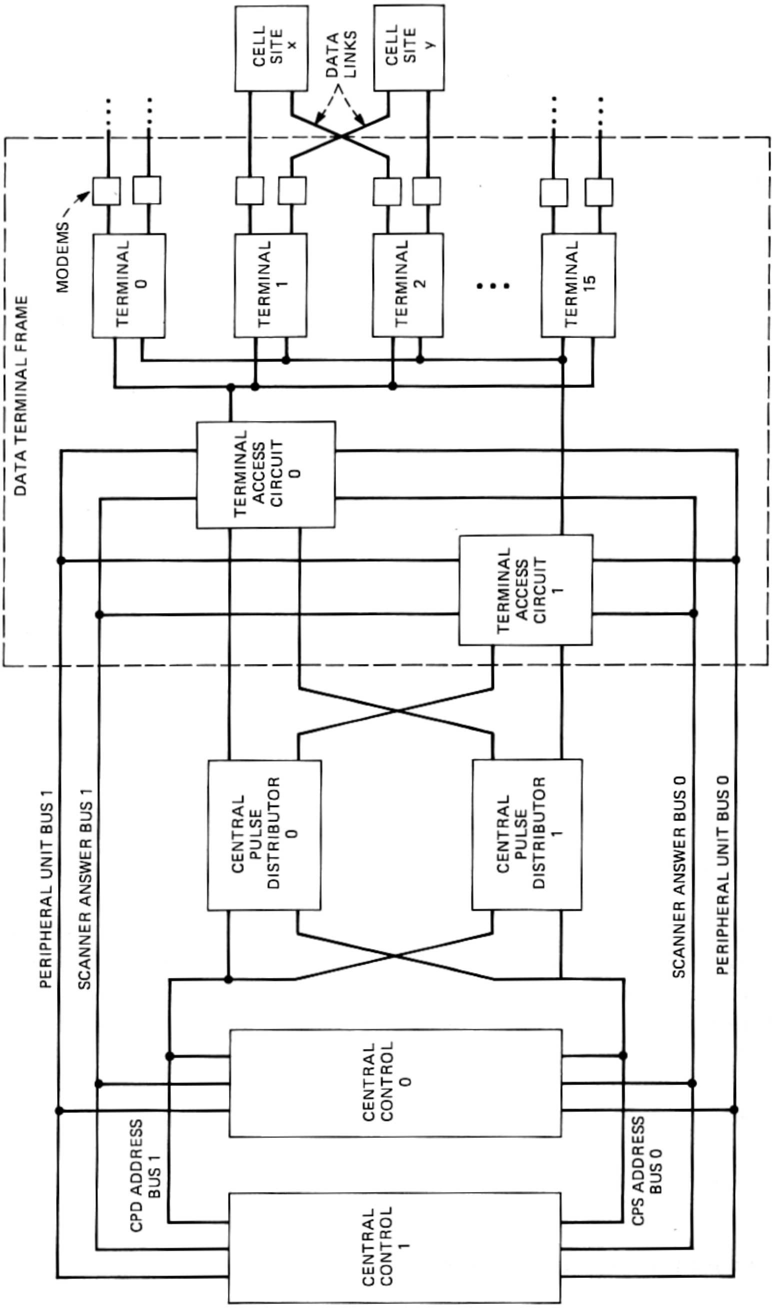


Fig. 10—Data terminal/cell site interconnection.

system: error strategy and fault strategy. The error strategy is utilized when the hardware failure cannot be reproduced (transient trouble). Isolation of the failing element is accomplished by error analysis of the peirpheral configuration existing during previous F-level interrupts. The fault strategy is used when the F-level recovery program is able to reproduce the hardware failure indication. The fault can then be isolated by repeatedly reconfiguring the peripheral system and retrying the failing peripheral order until no hardware failure indications are received. After a working peripheral configuration has been determined, the duplicate of the failing element is established as part of the active peripheral configuration and diagnostic tests are requested on elements containing faults.

An inherent characteristic of the fault strategy is that a hardware self-check failure must be reproduced to indicate the fault. When the fault strategy encounters a peripheral configuration which causes no hardware self-check failures, it is assumed to be a working configuration. Because of the complexity of the data terminal frame peripheral elements, the precise environment and failure mode of a faulted element cannot be reproduced with high certainty.

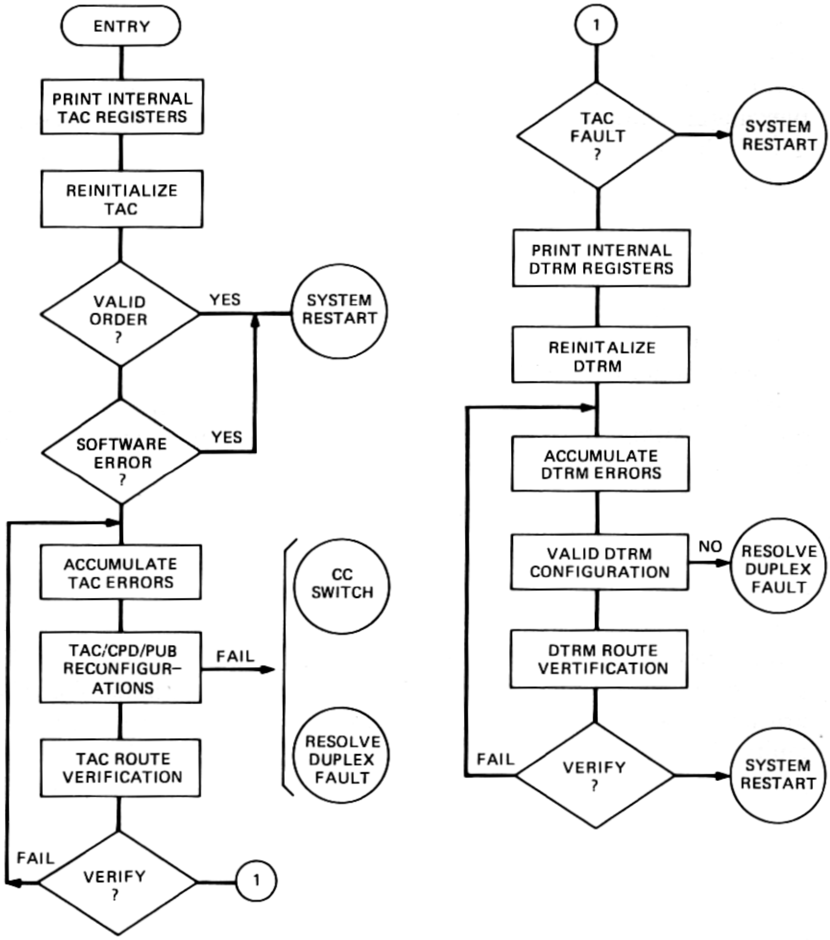
By not attempting to reproduce the environment in the data terminal frame which induced the F-level interrupt, the fault recognition process cannot isolate the faulty element; rather, a peripheral configuration is established by selecting elements which are least likely to be faulty. Unlike the fault strategy, here, the fault is not isolated to a particular inactive element, although the fault is known to reside in some element that has been removed from service. Diagnostics in this case will determine which inactive element(s) are faulty.

A prerequisite for error analysis is statistics gathering. On every F-level interrupt involving a data terminal frame order, records of accumulated errors are updated for active peripheral system elements. These histories are used to establish the next configuration to be tried upon the detection of an error. The interrupt recovery procedure is illustrated in Fig. 11.

6.3.2 Non-interrupt data terminal maintenance

The F-level recovery procedures are augmented by periodic reconfiguration and diagnostics. The standby data link and associated data terminal/modem are diagnosed immediately upon system initialization and at least once every several hours. Certain failures in the link diagnostic indicate that data terminal/modem problems may exist, in which case a data terminal diagnostic will be automatically invoked.

Since two cell sites share a data terminal/modem pair, the MTSO data link recovery programs must optimize the configuration of the terminals, cell controllers, and data links to maintain continuous communications to both cell sites. Since each cell controller can access all cell-site periphery, the data link configuration may ripple down and require a cell-site peripheral configuration.



TAC: TERMINAL ACCESS CIRCUIT
CC: CENTRAL CONTROL
CPD: CENTRAL PULSE DISTRIBUTOR
PUB: PERIPHERAL UNIT BUS

Fig. 11—Functional flowchart of data terminal frame, fault recognition.

6.4 Cell site maintenance

AMPS equipment differs from standard central office equipment in that a substantial portion of the common control hardware shared by all users is located remotely from the switching office. Since a remote cell site is an operational extension of the MTSO switching periphery, it requires the same high-quality maintenance considerations as if it were in the central office. AMPS uses a centralized maintenance scheme, with the majority of the cell site maintenance functions being controlled from the MTSO. The cell sites autonomously perform certain error-detection, correction, and quarantine functions. However, all actions associated with hardware reconfiguration, recovery, transmission testing, and diagnostics are under direct control of the MTSO.

6.4.1 Semi-autonomous cell site maintenance activities

Each cell site is equippped with two independent controllers arranged in a dual-simplex configuration. The controller is a self-checking entity; its static data structures are periodically updated by the MTSO. There is no direct interconnection between the two controllers. Each controller does, however, monitor the condition of its mate.

The cell-site controllers operate as independent multiprocessors. They are software-configured with respect to their periphery. The MTSO provides each cell controller with a mask of allowed periphery. The controllers' masks are mutually exclusive. Each peripheral can receive control signals and data from either controller. The controllers will partially execute all orders received over the incoming data links from the MTSO. The orders will be completed only if that peripheral is allowed to the controller. The active controller is normally granted access to all active peripherals. The standby controller is assigned only to work with the standby data link so that it may report errors to the MTSO concerning the active controller's state. In addition, for some maintenance actions, the MTSO may grant the standby controller access to the off-line, redundant equipment during diagnostic sequences.

The cell-site controller also performs some autonomous error-checking functions to determine its own sanity. The cell-site controller's program audits its internal transient memory structures to ensure that they are logically consistent. To perform this audit, the program utilizes the configuration data for the peripheral provided by the MTSO. In this way, access to the peripherals is limited and the cell site can establish whether or not its peripheral buffers are in a legal state. A cell site will attempt to restore its data memory where possible, by invoking one or more recovery actions when an error is detected. Depending upon the severity of the detected errors, the cell-site controller will notify the MTSO and/or update internal error counters.

The cell-site controller program also provides autonomous recovery from peripheral errors. The program will resynchronize the data links with the MTSO when link errors are detected. Single-bit errors are corrected for data received on the radio data links, and peripheral operations must be restored on parity or read failures. The cell-site controller increments internal counters whenever an error is encountered. These counters are read periodically by the MTSO. These counts are trended based upon expected error rates and are utilized to uncover transient failures or degraded hardware.

If the cell-site controllers lose communication with the MTSO for an extended period of time, they will inhibit data link communication and quarantine themselves from their peripherals. When this happens, the MTSO must restart and/or reinitialize the cell site to regain call processing capabilities. Alternative, fail-safe mechanisms are also provided to ensure that cell-site transmitters can be turned off even though cell communications have ceased. These are implemented via carrier presence signaling and autonomous cell-site timers.

When a controller hardware error is detected, the controller will be reset to a fixed address and execute sanity checks of the processor complex. If the sanity check executes normally, the controller is restarted. In such a case, the MTSO is notified that an error was detected and a recovery sequence has been run. However, if the error is such that the controller cannot execute the sanity check, the controller takes itself off-line. The standby controller then notifies the MTSO that its mate has encountered an error from which it cannot recover. The resumption of call processing by the standby controller is done only at the direction of the MTSO. Periodically, the cell controllers execute a subset of the sanity checks. If these fail, the controller will take itself off-line and quarantine itself.

6.4.2 MTSO-directed cell site maintenance activities

The cell-site maintenance strategy in the MTSO is to use reliable error indicators coupled with extensive error analysis before invoking any reconfiguration actions. Periodic functional tests are used to exercise the on-line cell site hardware. These tests are run in each cell interleaved with normal call traffic. The periodic functional tests are the primary fault recognition mechanism. A broad overview of the maintenance structure is shown in Fig. 12. The uppermost level in the diagram illustrates the gathering of information that describes the general health of the system. This information includes:

(*i*) Hardware faults from functional tests.
(*ii*) Autonomous cell hardware error reports.
(*iii*) Equipment alarms.
(*iv*) Error counts.
(*v*) Call failures.

Periodic functional tests are implemented by configuring the maintenance and test frame (MTF) in each cell site to simulate the functions of an operating mobile unit under automatic MTSO control. These tests consist of originating and terminating "calls" to the MTF, locating the MTF, performing handoff, and establishing audio continuity. The tests use the active cell-site equipment complement. These tests are interleaved with normal calls. During these tests, the maintenance and test frame is connected to the cell-site antenna system through the use of directional couplers so that the majority of the radio frequency equipment is included within the test loop. Failures or high-error rates in these tests are considered reliable indicators of cell site equipment problems. In addition, frequency and power tests are used as part of the periodic functional tests to aid in fault segmentation and to provide an early warning of degrading hardware modules. Another important periodic test is the frequency measurement of the cell-site system

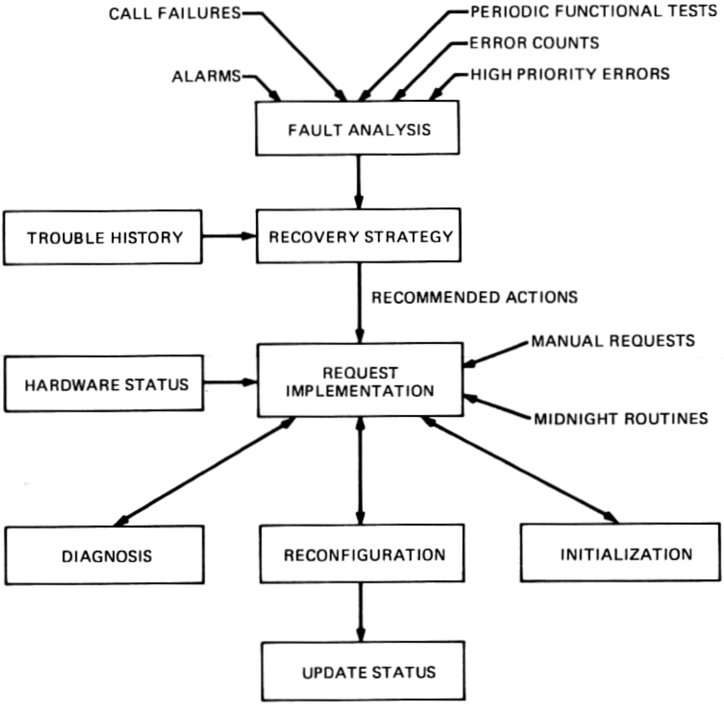


Fig. 12—Reaction to cell-site trouble.

clocks used to synthesize channels and radio carrier. The MTSO runs periodic diagnostic tests on the standby cell-site equipment to verify their readiness to assume active status if necessary. The MTSO will also attempt to diagnose each cell-site trunk at least once a day.

Failures detected during a call sequence are analyzed and logged by the maintenance system. This analysis detects abnormally high rates of failures and attempts to correlate hardware configurations with call failures and to identify malfunctioning equipment. Call failure error analysis is particularly aimed at trunks. If a unit is suspected to have malfunctioned, further tests may be scheduled. The combination of the above processes allows the maintenance system to detect failures reasonably free of the uncertainty due to radio frequency propagation and mobile unit failures.

The results of these tests are processed to determine a recovery action. If a particular unit appears faulty, it is placed out-of-service, and its duplicated mate, if applicable, is made active. The MTSO then initiates diagnostics on the suspected faulty unit. The diagnostics print results on the MTSO's teletypewriter indicating the action to be taken by the craft.

The next level of the cell-site maintenance structure implements the initial fault recognition and recovery strategy. Errors and fault indicators are mapped into a specific request for a maintenance action that is most likely to eliminate the trouble. A history of previous error reports and device status is maintained. This history is used to determine the next action. Depending upon the source of a maintenance request, the status of the cell, and past activity, a maintenance strategy is automatically generated. The ultimate strategy is to completely reinitialize a cell site. Follow-up work is scheduled after a maintenance action has been taken. Examples include diagnostics or transmission tests on equipment that has been taken out of service and the reinitialization of data link and cell-site units being placed in service. Craft personnel may also initiate any reconfiguration and/or diagnostic tasks.

MTSO-controlled cell-site equipment diagnostics are functional in nature. Segmentation is limited to subfunctions rather than physical circuit boards. Diagnostic access points are limited to the standard peripheral input/output ports and directional antenna couplers. Signals may both be injected and extracted via these couplers. The direction of these samples may be either incident to the transceivers or the antennas. Typical radio tests include:

(*i*) Baseband and radio frequency power.
(*ii*) Antenna tests including RF standing wave ratio and antenna gain balance.
(*iii*) FM deviation measurements.
(*iv*) Transmission quality and RF quieting tests.
(*v*) Frequency measurements.

In addition, the digital circuitry in the cell site is diagnosed. Typical digital equipment tests include:

(*i*) Data bus verification.
(*ii*) Parity generator/detector tests.
(*iii*) Flip-flop and memory pattern tests.
(*iv*) Logic sequencing and hardware lockout tests.

Loop-around facilities are provided on both the land data links and cell-site trunks. The diagnostics routines make extensive use of the looped facilities to perform both voice and data transmission quality tests. Many of the cell hardware components contain self-testing circuits. The diagnostics utilize the self-testing circuits primarily to aid in fault segmentation. Fixed voltage and frequency sources for meters and A to D converters are examples of the self-testing circuits in the cell site. Various self-checking circuits are also included in the cell-site hardware. The diagnostics periodically verify the operation of these circuits to ensure that these circuits will not incorrectly indicate a failed unit.

VII. SUMMARY

The Mobile Telephone Switching Office serves as the central coordinator for the Advanced Mobile Phone Service system. It provides the interface between the cellular mobile system and the land telephone network. The MTSO has two primary responsibilities. First, it controls the mobile telephone calls; second, it controls the automated maintenance activities of the system. The MTSO is implemented on the No. 1/1A family of Electronic Switching Systems.

VIII. ACKNOWLEDGMENTS

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