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16. Abstract

This report provides a discussion of the design of the DABS network management function.

Network management is responsible for the interaction between the local sensor and the adjacent connected sensors. Based on a dynamic interpretation of the coverage map and the status of the network, network management determines (a) the coverage responsibility of the local sensor, (b) which other sensors are covering the same area, and (c) which of the sensors has principal data link responsibility. Interaction is effected through message exchange over ground communication links connecting the DABS sensors.

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SECTION 1

1.0 INTRODUCTION

The Discrete Address Beacon System (DABS) is a beacon surveillance and communication system under development by the Federal Aviation Administration. The new system will provide for an evolutionary upgrading and replacement of the third generation Air Traffic Control Radar Beacon System (ATCRBS).

A key feature of DABS is the discrete address capability that is designed to eliminate such problems as synchronous garble and overinterrogation. DABS aircraft transponders carry a unique identification thus allowing selective interrogation (roll call). Because of the unique ID, sensors can easily correlate transponder responses to a record of previous reponses of the same target, and can exchange information about a DABS target without confusion. Periodically the DABS sensor will issue an interrogation designed to acquire a newly arrived DABS target whose ID is not yet known to the sensor. Such interrrogations are called "all-call" as opposed to the discretely addressed interrogations called "roll call." When a target is on roll call it is prohibited from answering the all-call and ATCRBS interrogation (it is "locked out"). When a target enters the zone of coverage of a new DABS sensor while being locked out by another sensor, the target must be "handed off." This is done through an exchange of ground communication messages between the sensors. The DABS sensor provides surveillance to ATCRBS transponder equipped aircraft as well. This is done by interspersing the schedules of discrete address interrogations with a series of ATCRBS interrogations.

A second key feature of DABS is its digital data link capability allowing high capacity, and reliable and responsive communication with the target. Improved reliable surveillance and direct digital communication are the features of DABS essential to automated air traffic control services such as Intermittent Positive Control (IPC) and Proximity Warning Indicator (PWI).

As noted already, the unique ID is an essential feature which allows quick exchange of information about a target between sensors. Ground communication exists for the purpose of handoffs. These features can be exploited to effect a close coordination and cooperation between sensors: sensors can assist each other for targets in areas of common coverage, sensors can adjust the extent of their coverage responsibility to incorporate the area of an adjacent sensor when that sensor fails, and messages can be uplinked to a target via several sensors in parallel if so desired. The DABS sensor is capable of stand-alone operation, but its most desirable features are strongly enhanced when it is used as a component in a network. A more detailed description of DABS is presented in Ref. 1.

The major software functions in the DABS sensor are network management, channel management, surveillance processing, data link processing, and performance monitoring. Channel management regulates the use of the RF channel in order to perform surveillance tasks with respect to DABS and ATCRBS targets and communications tasks with respect to DABS targets. Surveillance processing performs tracking of all targets. Data link processing manages the message flow of the ground-to-air data link. Performance monitoring routinely checks the operational status of the local and adjacent sensors. Network management is responsible for the interaction of the sensor with the network of sensors. The description of this function and the details of its design are the topic of this report.

Within the sensor, network management interacts mainly with data link processing and surveillance processing. It examines all messages coming from the sensor/user interface, and transfers the subset of uplink messages to the input buffer of data link processing. Network management is supported by surveillance processing via the surveillance file. Surveillance processing keeps target positions updated and indicates the nature and quality of the last received report, thus enabling network management to assess the need for network activity for each target.

The remainder of this report is structured as follows: Section 2 gives a general overview of network management. The general objectives of network management are realized through a set of tasks or routines, which are introduced in Section 3. The essence of these tasks is to make decisions and take action based on information accumulated in the network management files. The most important of these files are the coverage map and the network management lists described in Section 4. Action taken by network management results in updated files and an exchange of network control messages. The repertoire of messages, with their functional significance, is presented in Section 5. Sections 6 and 7 relate the details of the network management tasks, the triggers to the decision making process, and the outcome in terms of updated files and interaction with other sensors. This interaction is effected through a sensor interface that is responsible for the exchange of the messages, specifically the transmissions protocol and the formatting of the messages. The sensor interface is the topic of Section 8. Section 9 provides some detail on the interface between the DABS sensor and the local IPC function. Section 10 illustrates the main elements of network management activity for a single thread of flight.

SECTION 2

2.0 NETWORK MANAGEMENT OVERVIEW

The overall operation of network management is described in this section in terms of the key functions that must be performed. The definition of a set of processing tasks to accomplish these functions is covered in the following section.

2.1 Surveillance Control

When several sensors are deployed in close proximity to achieve low altitude coverage, they invariably provide multiple coverage at some higher altitude. Since one of the fundamental DABS assumptions is that aircraft should be locked out to all-call whenever possible in order to reduce unnecessary transmissions on the link, an alternate mode for acquisition must be provided. As an aircraft proceeds from the coverage of one sensor into the coverage of an adjacent one, if that aircraft has been locked out to the all-call acquisition mode, the second sensor will not be able to acquire the aircraft by itself. The surveillance control feature of DABS is concerned with having the first sensor send appropriate handoff messages so that the second sensor can acquire the aircraft by discrete address interrogations only. In addition to this handoff function between sensors, surveillance control is concerned with determining which aircraft should be locked out to all-call acquisition and to ATCRBS and in what parts of the coverage. This determination of lock out versus coverage will have been preloaded into the coverage map stored in each sensor. The coverage map will be examined as the aircraft proceeds along its path and the appropriate bits will be set to cause lock out to be inserted or removed. In addition, the map will be examined in much the same manner to determine if an aircraft should not be roll called. This permits the sensor to carry a track in its track file using data only from an adjacent sensor, but not performing the roll call interrogation itself. An incidental feature is to read the coverage map and determine for each location what the altitude adjustment should be for the purpose of retransmitting the altitude echo (ALEC) back up to the aircraft.

2.2 Track Data Exchange

If a sensor has been tracking an aircraft satisfactorily and then loses data on it so that the track goes into a coast, it requests data from its neighbors, uses that data in its track file, and attempts to re-establish roll call data of its own. In addition, if the IPC function at a given sensor desires data on a track from an adjacent sensor, it can request that data. A third reason for track data exchange is the presence of an aircraft in an area close to the site called the zenith cone. The local sensor then wants external data to be available in anticipation of a fade. The track data exchange between sensors involves the use of five different kinds of messages. The first one is sent by the sensor wanting data, and is called a data request message. This same message, incidentally, is used by primary control (discussed in subsection 2.4) to effect a temporary handoff of primary responsibility. When the sensor has received all of the data it wants from the adjacent sensor, it then sends another message called the cancel request message. This not only indicates that no more data are required on that track, but may also be used to rescind the primary assignment that was temporarily given off before. When a remote sensor receives a request for data on a given track and is able to comply by virtue of having the track on its roll call, it will send a series of messages, the first one being a data start message followed by a track data message (one per scan) until such time as the request for data is cancelled; finally, it will send a data stop message. Network management is responsible for keeping account of these various messages going back and forth, and receiving or sending the data that has been requested. In the case of data that has been requested, network management selects the data from the track file and sends it out over the interfacility communications to the adjacent site. In the case of data that has been requested, when the data arrives network management is responsible for routing it to the proper user. If it has been requested for the use of the sensor proper, network management will do the appropriate coordinate conversion and hand the data over to surveillance processing. If the data were requested by IPC, the data are routed directly to IPC.

The track data exchange described here applies to DABS targets as well as ATCRBS targets having Mode C (altitude reporting) capability.

2.3 Failure and Recovery Modes

In a network of several normally operating sensors some forms of failure may occur. The sensors routinely exchange status messages among themselves, so that each one knows when its neighbors are operating satisfactorily. Two kinds of failures are identified. The first one is where a particular sensor, in monitoring its own performance, concludes that it is unable to perform satisfactorily and sends out a message indicating that it is in a state of failure. In that case, its neighboring sensors know that the sensor has failed; this is called a positive failure. A second type of failure occurs when a given sensor is communicating with one of its neighbors and suddenly the communication stops; satisfactory messages are not received. The sensor doesn't know for sure whether the other sensor has failed or whether the communication line between the two sensors has failed. This is known as an inferred failure. It is inferred that a failure has occurred, but certain precautions are taken until the inferred failure status can be resolved. This resolution takes place by exchanging messages with other sensors that are connected to the presumed failed sensor by an alternate communications route.

It is the responsibility of the sensor performance monitoring function to detect these positive or inferred failures and signal this to network management, which will then take the appropriate action that results in a reconfiguration of the network so that satisfactory service is provided to the aircraft.

The reconfiguration has been stored in the coverage maps as part of site adaptation. Two modes of reading the map are possible: one when all sensors are operating normally, and one where a failure of an adjacent sensor has been declared. If only an inferred failure has been determined, the presumption is that the sensor itself is still operating. In that case, it is necessary that the aircraft proceeding across the boundary toward that sensor with which communication has been lost be unlocked so that they can be acquired on that sensor's all-call interrogation. In this way, the aircraft will not come into the coverage of that sensor undetected. For either positive or inferred failure, the coverage boundary of the adjacent sensors automatically extends to attempt to do tracking and data link in the area where a failed sensor has been doing the tracking and data link.

2.4 Primary Control

Certain functions that the sensor is able to perform are desired to be performed by only one sensor at a time. Synchronized interrrogations to permit one way air-to-air ranging, ALEC, and readout of downlink messages are the three principal examples. IPC, ARTS, and the En Route control centers are expected to use the indication of primary sensor to determine which sensor is the one to be used as a first choice whenever more than one sensor are available. Whenever more than two sensors are able to see and track a given aircraft, a determination must be made as to which of the two sensors shall be called primary and which shall be called secondary. Network management is responsible for examining the coverage map for each aircraft to determine if it is in a location where that sensor should be primary. If the aircraft moves from one location to another, network management shall determine if a change in primary assignment is required and, if so, exchange appropriate messages with adjacent sensors to effect a positive handoff of primary responsibility. In addition, network management is responsible for examining the track status of the aircraft. If a track had been receiving good data on roll call on previous scans and suddenly goes into a "coast" mode, then network management must inform an adjacent sensor that it is no longer in contact with the airplane and temporarily assign its primary responsibility to the adjacent sensor. At the same time, network management requests (from that adjacent sensor) that track data be sent on the track that has been coasted. At a later time, if the sensor is able to rollcall a track and put it back into normal tracking, the sensor will notify its neighbor that it is tracking normally and rescind the temporary assignment of primary responsibility. During the time that a sensor is supposed to be primary according to its map, but has given away this responsibility on a temporary basis, that sensor assumes a status known as temporarily secondary. As each of these transitions takes place, the sensors exchange appropriate messages so that at any given time one, and only one, sensor is primary and all of its neighbors know which one it is.

A new track that has just been acquired in the all-call process could be in a transition zone between two sensors. A transition zone is one where, depending upon how things get started, either sensor is authorized to be primary. Consequently, messages are exchanged between the two sensors to notify each other that they have the track and to ask for or grant primary status. The exchange is arranged so that in case of a tie there is an automatic tie breaker, and only one sensor becomes primary at a time.

2.5 Interface Control

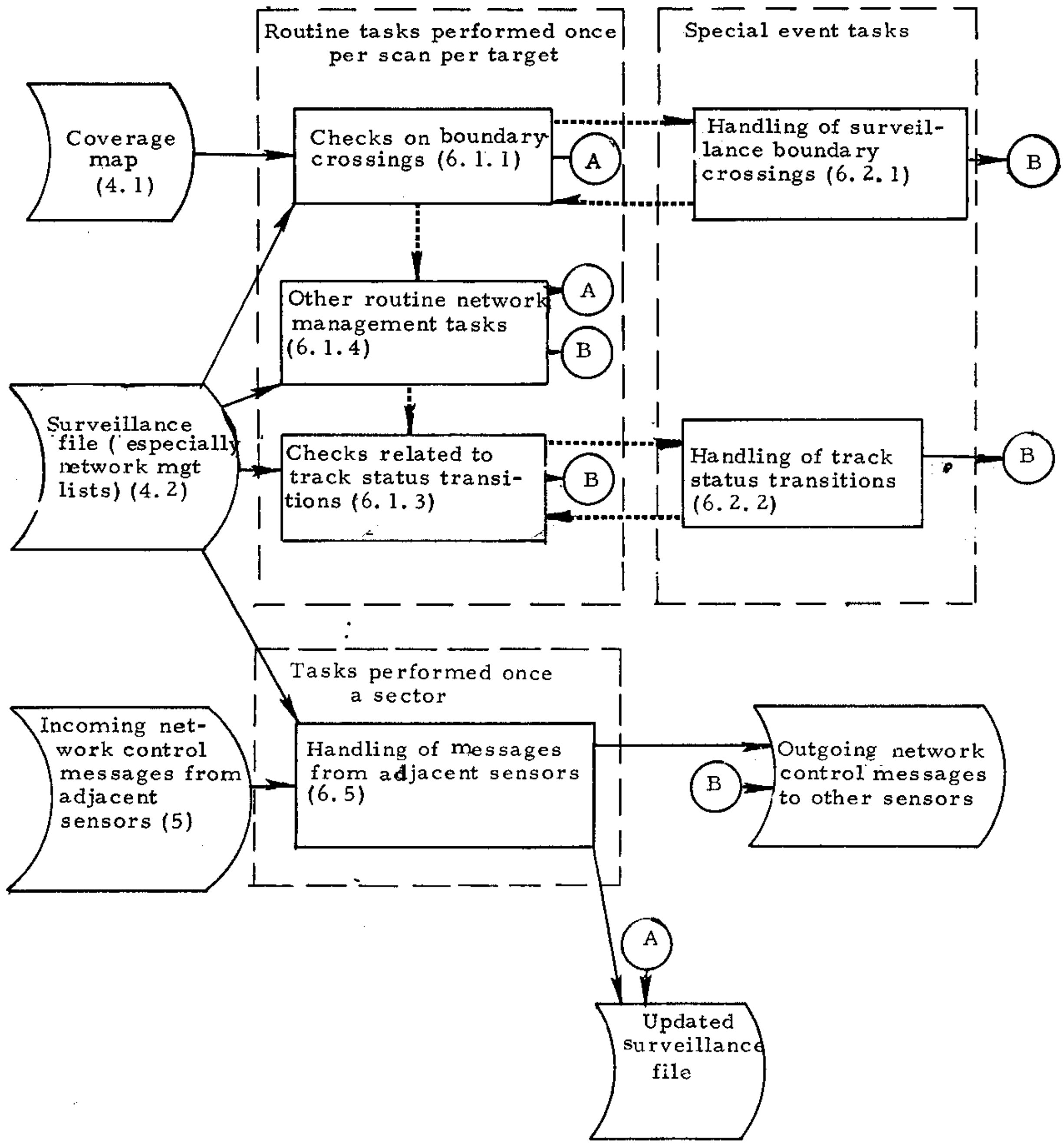
All communications between facilities have to be done in a certain format and following an established set of rules and procedures. Part of network management, called message routing, examines all incoming messages and routes them to the appropriate user within the sensor. Message routing generally is also responsible for formatting a class of output messages from IPC destined for users outside the sensor. An example of this is when the IPC at a given site may wish to send a data link message to an aircraft by way of all available links. In order to do this, IPC merely tags the message as "multilink." The message will then be sent by network management to the local data processing function and be routed to adjacent assigned sites, the identities of which are not known to IPC. When the data link message arrives at the other site, network management will read the incoming message, determine by looking at its address and type that it is intended for data link processing, and will put it into an appropriate buffer so that data link processing can have it sent up on the uplink.

Essentially, network management in this capacity is just a switchboard sending messages to the appropriate subfunctions within the sensor as they arrive over the interfacility communications link.

SECTION 3

3.0 NETWORK MANAGEMENT ARCHITECTURE

The several subfunctions comprising network management are executed each on their own time scale. For example, surveillance control monitors the need for the exchange of track data on a once per scan per track basis and takes action for setting up the data exchange when such need has been established. The track data exchange function from then on executes the data exchange once a scan for every target involved. Surveillance control, primary control, and track data exchange are the basic once per target per scan functions. They operate on all targets in a sector soon after the sector is released by surveillance processing and more or less synchronously with the beam. These tasks will be referred to as routine network management tasks. The routine tasks constitute a series of checks for each target. If the check turns out to be positive, an "event" has occurred and some special action is needed. One such event is the crossing of a boundary on the coverage map or the transition of the status of the track from being maintained on external track reports to being supplied with local track reports. Tasks associated with such events will be further referred to as special event tasks. A different kind of special event is a change in the status of a component of the network. Sensor failure (declared or inferred) and recovery fall in this category. Communications with adjacent sensors resulting from failure or recovery activities are time critical. Reaction time at the adjacent sensor is determined by the maximum time interval allowed to empty the buffer of incoming messages. The handling of incoming messages is done at time intervals not larger than 1/16 of the scan time. Outgoing messages are generated as a result of other network management tasks and therefore occur as required throughout the scan. An exception to this is the issuance of special communications that occur once a scan. Such communications are the dissemination of the Northmark Message, Sensor Status Messages, and the Track Alert Message. Figure 1 presents a block diagram of the network management tasks. The inputs to the network management tasks are data stored in the files (see Section 4) and messages. The outputs are data stored back in these or other files and messages. The interaction between files and tasks is illustrated in Fig. 1.



Key: ---- sequence of execution
—— flow of information

Fig. 1. Network Management Tasks - Block Diagram

SECTION 4

4.0 NETWORK MANAGEMENT FILES

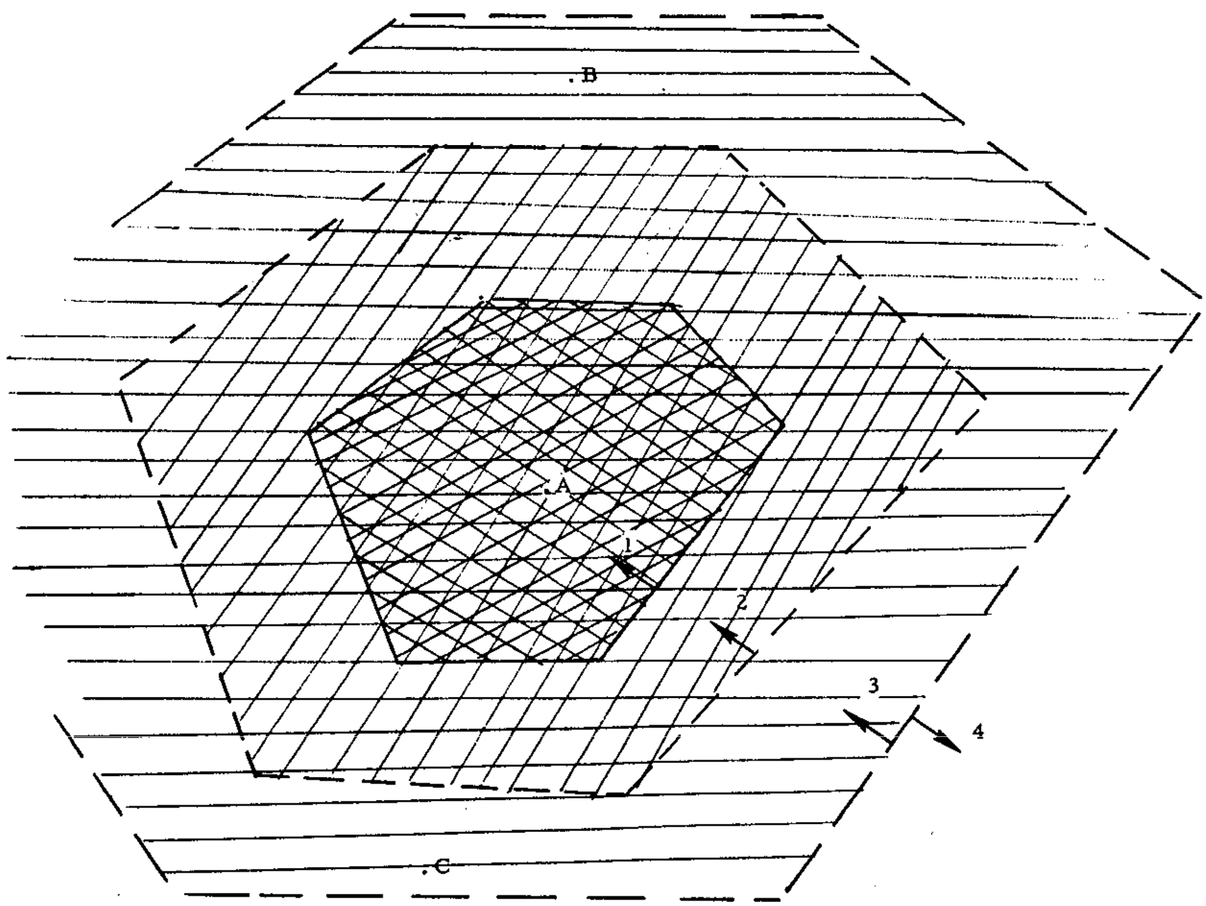
There are basically two major files in which all information recorded for network management decision making is stored. The first file is the coverage map, further described in subsection 4.1; the second file is the surveillance file. Only part of that file, further referred to as the network management lists, is both read and written by network management. The network management lists are described in subsection 4.2.

4.1 The Coverage Map

4.1.1 Sensor Assignment

The principal purpose of the coverage map is to provide coverage assignments, i.e., the designations of which sensors are expected to provide surveillance at each point in space. From the viewpoint of any one sensor, its volume of potential coverage is divided into subvolumes (Figs. 2a and b). In a first subvolume the local sensor is required to provide coverage and is in fact the "best" or primary sensor. In a second subvolume the local sensor is still required to provide coverage but is not the best situated sensor; it is a "secondary" sensor. The implications of this priority ordering will be explained in subsection 6.4. The first two subvolumes will be collectively referred to as the required airspace.

In a third subvolume the sensor may exercise surveillance in special circumstances only, such as to provide backup coverage in the event of an adjacent sensor failure. This third volume will be referred to as the permitted airspace. Finally in a fourth subvolume called the forbidden airspace, the local sensor is never allowed to track a target. The rationale behind the concept of the forbidden airspace is to cover the situation where a sufficient



Key 1: A is primary and required
2: A is secondary and required
3: A is permitted or back-up
4: A is forbidden

Fig. 2a. Assignment areas for sensor A.

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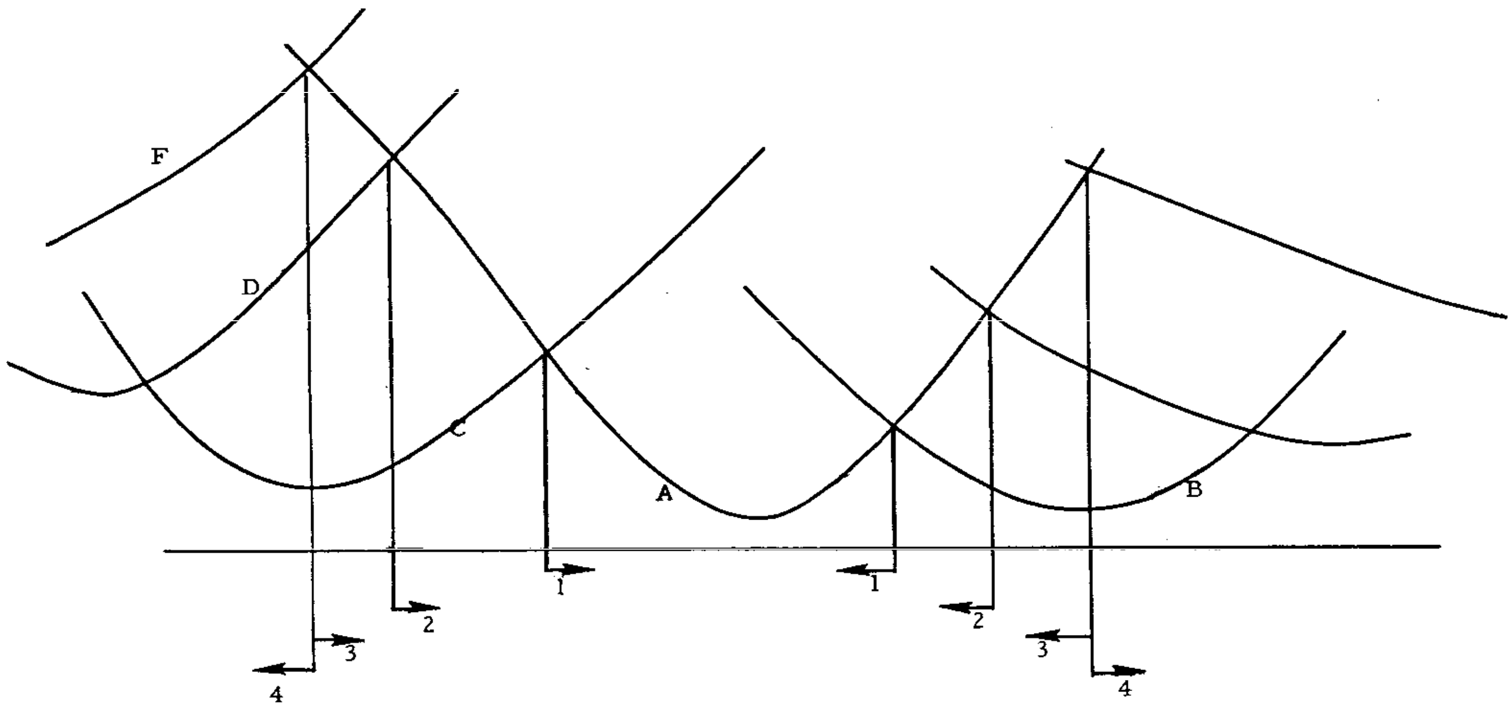

Fig. 2b. Vertical assignment areas for sensor A.

number of other sensors are better sited to provide coverage. Also, as a rule, a sensor will not be allowed to provide coverage when the same airspace is covered by a remote sensor which is not directly connected to the local sensor with ground communications lines. Establishment of forbidden airspace will prevent a target from being captured by one sensor while better sited sensors are unable to acquire because they cannot communicate with the first sensor.

Determination of the extent of the required, permitted, and forbidden airspace for a particular sensor can be done once all sensors in a network are sited and all physical coverage limitations are known. It should be clear that addition of a sensor to an already existing network of sensors will require redefinition of the airspaces of a number of adjacent sensors and thus result in a new coverage map for each of these sensors. The determination of the extent of the several airspaces can only be done after a detailed study of specific site conditions, topographical features of the surrounding terrain, and the geometry imposed by the choice of the location of the sites.

Once the coverage capability of each sensor is determined, the theoretical coverage assignments can be made at each point in space. On a vertical, the first assigned sensor will be the one that can provide coverage at lowest altitude according to the coverage capability model. Where no obstructions interfere, this will be the closest sensor. The second assigned sensor is the one whose coverage cone is entered next, going vertically upwards. For practical reasons at most a third sensor is selected for assignment at higher altitudes, even if many other sensors may be capable of coverage. In general the rules of assignment select sensors in an order which gives the highest probability for successfully interrogating a target according to the constructed coverage model. The first assigned sensor however will be assigned down to ground level, i.e., will try to interrogate a low flying target as long as possible.

4.1.2 The Coverage Map File

The theoretical assignment derived from the coverage model must be efficiently stored in computer memory. The three-dimensional space will therefore be quantized and the identity and relative importance of the assigned sensors determined for each incremental volume. The types of problems encountered due to quantization, such as different assignment readings on maps of adjacent sensors for the same point in space, depend largely on the choice of coordinate frame used to describe the airspace. One choice of coordinates could have been the Cartesain x-y coordinates combined with a stereographic projection. However, the needs of channel management and of surveillance processing dictated the use of a polar (slant range, azimuth, altitude) coordinate frame. In this frame the incremental volume of airspace (in terms of which coverage assignments are expressed) is the vertical airspace above the areas specified by two ranges and two azimuth values. This area will be called a cell of the map. The range and azimuth increments are chosen to be range dependent in order to ensure a more or less constant cell area. A detailed description of map quantization and an example of the construction of a coverage map are given in Appendix A. For each cell, an ordered list of sensors is provided indicating in order the sensor that is primary, secondary, and "permitted" or backup for the cell. This ordering is further refined by the specification for each sensor of an altitude breakpoint. An altitude breakpoint represents the coverage capability of a sensor in the vertical dimension. Specifically, it is an approximation to the lower edge of the cone of coverage of the sensor in the particular cell of the map. Table 1 summarizes the kind of information that is stored for each cell. The first field specifies a parameter Maximum Number of Assigned Sensors (MNAS) which is the number of sensors assigned in that cell for a high altitude target. Cells that have the same sensors listed are said to belong to a subarea. The second field in each cell is a pointer to the subarea. Fields 2 and 4 are the altitude breakpoints for each of the sensors. The coverage area for a given sensor may have several altitude correction zones. Field 5 is a pointer to a particular zone entry in the list of altitude adjustments, periodically updated by the ATC facility.

Fields 6 to 12 express the fact that the cell belongs to a particular area; field 6 signifies whether DABS targets should be locked out to ATCRBS interrogations in the given cell; field 9 whether DABS transponders are to be put into a mode that allows all call interrogation by auxiliary sensors. The special purpose of auxiliary sensors is to ensure continuity of synchronized service in areas not covered by a standard sensor.

TABLE 1

DEFINITION OF FIELDS IN THE COVERAGE MAP

Field		
Field 0	The value of MNAS for this cell.	2 bits
Field 1	A pointer to an entry in a short list of sensors for each subarea.	5 bits
Fields 2, 3, and 4	Altitude breakpoints for the sensors listed in the subarea list. Value range (500 - 50,000, 500) feet.	3 x 7 bits
Field 5	A pointer to an entry in a short list of altitude correction values.	(≤ 4 entries) 2 bits
Field 6	The ATCRBS lockout bits.	1 bit
Field 7	Primary flag to indicate if the local sensor is the primary sensor on the map.	1 bit
Field 8	Transition zone flag to indicate if this cell belongs to the transition zone of the map.	1 bit
Field 9	DABS lockout transition control bit to signal whether DABS targets should be unlocked for auxiliary interrogators.	1 bit
Field 10	Zenith cone flag to flag proximity to the site.	1 bit
Field 11	IPC responsibility indicator to identify which of the sensors listed has IPC responsibility.	3 x 1 bit
Field 12	Roll call inhibit indicates that tracks in this cell are to be maintained on external data only.	3 x 1 bit
Field 13	Sensor IDs.	3 x 4 bits
Field 14	Altitude correction. Value expressed in special BCD, using 1 bit for sign and 7 for numerical values in hundreds of feet (3 bits for the thousands, 4 bits for the hundreds).	8 bits.

Fields 7 and 8 determine in part the "sensor priority status" (subsection 6.4). Field 10 indicates close proximity to the site. Network management will react to this by requesting track assistance from other sensors in anticipation of a zenith cone fade. Field 11 indicates which of the sensors listed has IPC responsibility. Field 12 signals which sensor is roll call inhibited. A roll call inhibited sensor that is assigned (also referred to as a passively assigned sensor) must track targets based on external data but cannot roll call them in the given cell.

When and how the several fields in the map are to be read and used is covered in the description of the network management tasks in Section 6.

4.2 The Network Management Lists

Part of the record of each DABS target in the surveillance file is made up of fields of information used primarily by network management. For ease of description and reference, the fields of information are grouped as lists and will be referred to as the target status list, in-list, out-list, and network management output list.

The target status list contains information on the status of the track with respect to network management controlled track data exchange, on the coverage assignment over the same target by adjacent sensors, and on a track data request having been received or issued, etc. The in- and out-list contains information pertaining to track data being received from or sent to adjacent sensors. The output list contains information formulated by network management for the use of other sensor functions, such as channel management and data link management.

Table 2 presents an overview of the fields that the network management lists may contain. Certain fields need not be actively used by all targets. What is shown are the maximum number of fields and the field length in order to allow an assessment of storage requirements.

4.2.1 The Target Status List

For network management purposes, the track quality S can be described by one of five possible values: the track is either maintained on all call

TABLE 2

FIELDS IN THE SURVEILLANCE FILE FOR NM

Type of List	Component	Symbol	Number of bits
Target status	Target track status	S	3
	Sensor priority status	PS	3
	Permanent handoff in progress	PHP	1
	Request bit	TR, TRR	2
	IPC request bit	IR	1
	First adjacent assigned sensor	Sensor ID	4
	Its request bit	RR	1
	Second adjacent assigned sensor	Sensor ID	4
	Its request bit	RR	1
	Coverage map cell index (last 8 bits)	IQ	8
	Special mode flag	SMF	1
	Data link activity flag	DLAF	1
In	First sensor ID	Sensor ID	4
	Flag for active use	AF	1
	Second sensor ID	Sensor ID	4
	Flag for active use	AF	1
Out	Flag to suspend action on this target	OSE	1
	Expiration counter	OEC	3
	First sensor ID	Sensor ID	4
	Second sensor ID	Sensor ID	4
Network mgt. output	Altitude correction (in BCD)	ΔH	8
	ATCRBS lockout bit	AL	1
	DABS lockout transition control bit	AUX	1
	DABS lockout bits	DL	2
	Sensor priority bits	SPB_1, SPB_2,	2
	Roll call inhibit flag	RCI	1

($S = S_2$), local roll call ($S = S_4$), external roll call reports ($S = S_3$), the track has been coasted without reports for at least one scan ($S = S_1$), or the track has just been started and no quality determination has as yet been done ($S = S_0$).

The assigned sensors have a certain priority status (PS) with respect to each target. PS may assume one of five values: permanent primary (P), temporary primary (P_T), permanent secondary (S), or temporary secondary (S_T) or, neutral (N) when the priority status has not as yet been determined. The PS value is, in general, dictated by the coverage map. The two major exceptions occur when a target enters a prolonged fade condition or when the coverage map is ambiguous in the priority assignment. Subsection 6.4 explains the PS assignment in detail.

The position of the target on the coverage map is retained by storing the cell index in the target status list. Also recorded is the set of assigned sensors other than the local one. When the local sensor requests external track data, the reason for the request is recorded: bit TR if data are requested because of a fade, TRR if the target has entered the zenith cone, or IR if external data are requested by the local IPC function. The RR bit records whether the particular assigned sensor has requested data from the local sensor.

The special mode flag (SMF) in the target status list signals that an adjacent sensor has failed and that the coverage map must be interpreted in a different mode to make up for the lost coverage capability. The data link activity flag (DLAF) signifies that the local sensor is in the process of downlinking a message and that handoff of authority to downlink messages to another sensor (handoff of priority status P) must be delayed.

4.2.2 The In List

When track data are being received from an adjacent sensor, its ID is recorded in the In List. Since several sensors may be sending data simultaneously, the local sensor must make a selection in order to use data consistently from the same sensor. This is done by the setting of the active flag (AF).

4.2.3 The Out List

When the local sensor starts sending track data, either because it is complying with a request or has found the adjacent sensor to be newly assigned and in need of a handoff, the identity of that sensor is recorded in the Out List. Once recorded there, the sensor will receive track data on a routine basis.

If for some reason the local sensor can not (or can no longer) comply with a request for data (for example because it experiences a fade itself), activity on the Out List is temporarily suspended by setting the OSE flag. If service cannot be resumed within OECT = 5 scans, as counted by OEC, the entry in the Out List is erased; otherwise the counter is reset to zero, the flag in OSE is reset, and normal outputting activity resumes.

4.2.4 Output List

This list groups elements that are outputs of network management and are mainly used by channel management and data link processing. These elements are the altitude adjustment value ΔH used by channel management to form the altitude echo (ALEC), the ATCRBS lockout list signaling to channel management to lock out the DABS transponder to ATCRBS interrogations, the DABS lockout transition control bit signaling not to lock out the transponder to DABS all call interrogations from an auxiliary sensor, and the two DABS lockout bits. These bits are used by channel management to set the state of the transponder in which it does or does not comply to standard all call interrogations or auxiliary discrete address interrogations [Ref. 4]. The output list also contains a roll call inhibit flag (RCI), which when set, signals to channel management that no interrogations should be scheduled for this target at this time. Finally there are the sensor priority bits. The setting of the first bit (the primary bit) to one signals to channel management and data link processing that the local sensor has the responsibility for downlinking pilot originated air-to-ground messages. The second bit (the synchro bit) signals that the local sensor will provide synchronous interrogations and the altitude echo (ALEC) service.

SECTION 5

5.0 NETWORK CONTROL MESSAGES

Table 3 consists of a list of control messages used by network management. Messages 1 through 5 relate to establishing or canceling the flow of track data between sensors. The messages in parentheses refer to exchange of track data on ATCRBS targets.

TABLE 3

REPERTOIRE OF NETWORK CONTROL MESSAGES

1. Data start (ATCRBS data start)
2. Data stop (ATCRBS data stop)
3. Data request (ATCRBS data request)
4. Track data (ATCRBS track data)
5. Cancel request (ATCRBS cancel request)
6. Track data request/cancel (ATCRBS data request/cancel)
7. Permanent handoff
8. Accept permanent handoff
9. Coordination in transition zone
10. Track alert

Message 6 is a message sent by the local IPC function to the local sensor in order to request or cancel the request for external track data on a particular target. In response, network management will issue a data request or cancel request to the appropriate adjacent assigned sensors (which are unknown to IPC).

Messages 7, 8, and 9 are used in establishing the priority status PS of a sensor with respect to a particular target. Message 10, the track alert message, is used to alert adjacent assigned sensors to the existence of two DABS targets carrying the same code.

The functional significance of the principal network control messages (1 through 5) can be best explained in an illustration of a track data exchange. Assume therefore, that sensor A experiences a target fade, or a target enters its zenith cone, or the local IPC requests external data. Sensor A will issue a track data message to the other assigned sensors. The number of these sensors for a target at sufficient altitude is determined by the parameter MNAS. Since nominally MNAS equals two, only one adjacent sensor is assigned whenever the local sensor is assigned. The network management design, however, allows MNAS to equal three. Three sensors will be assumed for the example, with the other two sensors labeled B and C.

Sensors B and C receive the message and assume that sensor B is unable to comply because it is experiencing difficulties with the same target. It will then answer with a data stop message, but will keep a record of the request. Sensor C is able to comply and answers with a data start message followed scan-by-scan by a track data message. Assume now sensor B resumes normal tracking. It will then issue a data start followed each scan by a track data message. Sensor A uses data from only one sensor (from sensor C in our example since it was the first to respond). When sensor A resumes normal operations it issues a cancel request message to all sensors that are providing track data. These sensors acknowledge with a data stop message.

A different scenario for track data exchange occurs when a sensor determines from its coverage map that a target has entered the required coverage volume of an adjacent sensor. Since that sensor cannot acquire the target because of the DABS lockout status of the transponder, the local sensor must assist in establishing a track record. The local sensor therefore issues a data start and track data messages used by the adjacent sensor to rollcall the target. Track data messages are provided until a cancel request is received which is acknowledged with a data stop. Section 10 illustrates a scenario with the corresponding network management activities.

The data request, cancel request, and data stop messages contain a field called "temporary primary handoff indicator" (see formats of messages in Appendix B). The role played by this field and the meaning of the messages 7 to 9 will be explained in more detail in the context of establishing sensor priority status (subsection 6. 4).

SECTION 6

6.0 NETWORK MANAGEMENT TASKS

Major network management activity, with respect to a particular DABS target, is triggered by any of three basic events: surveillance boundary crossings, changes in track status, and the receipt of control messages from adjacent sensors. Such activity consists of updating files or issuing messages or both. If, for example, the event is a boundary crossing whereby a new sensor becomes assigned to cover the target, a data start message is issued to that sensor. At the same time, the out list is updated by adding the sensor ID in order for the effect of the boundary crossing to persist. Once a scan, all entries in the out list are sent a track data message until a new event occurs, namely the receipt of a cancel request message.

The network management tasks can be divided into five categories. The first category consists of the routine tasks performed once per scan for each target, such as the servicing of entries in the out list with track data and routine checks designed to detect surveillance boundary crossings and track status changes (subsection 6.1). The second category consists of tasks related to these target related events (subsection 6.2). The third category relates to sensor failure and recovery (subsection 6.3). A fourth category involves the determination of the sensor priority status with respect to each target. This task is executed each time the map is accessed using the input of the coverage map and the surveillance file. It is also executed at receipt of special sensor control messages (subsection 6.4). A last category of tasks relates to the processing of incoming sensor control messages (subsection 6.5).

6.1 Routine Network Management Tasks

6.1.1 Checking for Changes in Surveillance Assignment

Surveillance assignment is dictated by the coverage map on a per cell basis, and by the mode in which the coverage map is being interpreted. If the target is in the same cell and the map is read in the same mode during this scan as was the case the previous scan, the surveillance assignment and all information read from the coverage map will be the same. The first check, therefore, consists of calculating the cell index and observing the mode of this scan and comparing it to the same parameters obtained on the previous scan and stored in the track status list. Further action will be taken only if the cell index or the operating mode has changed. In this case the new set of assigned sensors must be read from the coverage map. If the set of assigned sensors found this scan differs from the set found on the previous scan, a surveillance boundary has been crossed. This event causes action that is further described in subsection 6.2.

6.1.2 Transfer of Information from the Coverage Map

When the coverage map is accessed, a series of incidental tasks based on fields of information in the map are also performed.

The primary flag and the transition zone flag for the given cell are read and used as inputs to the sensor priority status determination function described in detail in subsection 6.4. The priority status value returned by that function is then used to determine the sensor priority bits. Specifically if the value of the priority status PS equals P (primary) or P_T (temporary primary), both sensor priority bits, SPB_1 and SPB_2, are set equal to one. This signals that the local sensor will perform the task of downlinking pilot originated air-to-ground messages ($SPB_1 = 1$) as well as providing synchro and altitude echo service ($SPB_2 = 1$). If the sensor priority status value returned is not P or P_T, SPB_1 is set equal to zero. The priority bit SPB_2 is set equal to zero if PS = S, and to one otherwise.

Several parameter values found in the cell of the coverage map are transferred to the network management output list of the surveillance file.

They include the altitude adjustment value ΔH to be used by channel management when formulating the altitude echo (ALEC). Also transferred are the ATCRBS lockout bit and the roll call inhibit bit. Transfer of the DABS lockout transition control bit depends on the target altitude.

If an auxiliary sensor is a neighbor to the local sensor, part of the coverage area of the map will have the DABS lockout transition control bit set. This simply indicates that the DABS target should be unlocked for the interrogation of the auxiliary sensor before the target leaves the zone of coverage of the local sensor. The unlocked target can then be acquired by the auxiliary sensor. Deliberate unlock will thus permit continuity of surveillance, which is essential for the continuity of the synchro service. The decision rule to unlock is: if the cell has the lockout transition control bit set, and if the local sensor is the only assigned sensor, and if the target altitude is smaller than the altitude breakpoint of the local sensor, and if the DABS lockout transition control bit for the given target is not already one, then the latter is set equal to one and the DABS lockout bits are set equal to zero in the network management output list. If the DABS lockout transition control bit on the map is zero, it is also set to zero in the output list and both the DABS lockout bits are set to zero. Each time channel management reads AUX = 1, followed by DL = 00, it will schedule an interrogation (or interrogations) to force the transponder into a particular state in which it answers all-call and discrete interrogations from an auxiliary sensor. If channel management has been successful, the DL bits will have been reset (by data link processing) to 01. Each time the coverage map will be accessed (which is nominally when the target has entered a new cell) and the map interpretation yields an AUX value differing from the one in the network management output list, the whole procedure to lock or unlock for the auxiliary sensor is repeated.

If the target is in close proximity of the sensor, the zenith cone flag in the corresponding cell of the map is set. This indicator causes the local sensor to request track assistance from adjacent sensors in anticipation of a target fade associated with the penetration of the cone of silence. The specific action consists in issuing a data request message to all other assigned sensors.

In order to keep a record of reason for this action, the request bit TRR in the track status list of the surveillance file is set. Figure 3 summarizes the activity described in subsections 6.1.1 and 6.1.2.

6.1.3 Checking for Track Status Changes

The track status is determined by the reply type associated with DABS position reports. In particular the reply type may indicate that the report is an external report, a local all-call report, a roll call report, or it may indicate a missed reply. In the latter case, the value returned by the coast counter is important in determining the track status value or track state.

Once per scan per DABS target, the reply type and the coast counter associated with the last scan are compared to the track state of the previous scan. If no track state was stored on a previous scan (state S_0) such as could be the case for a new track, the reply type determines the status. In such case, the reply type will normally be all-call so that the status value will be S_2.

Track states S_1 and S_2 are usually of short duration. State S_1 is assumed if no replies are received on a given scan. Transition into S_1 triggers a call for external data. If this is not possible (either because no other sensor is assigned or the other assigned sensor(s) cannot provide data) and if the local sensor does not re-acquire, the track will soon be dropped by surveillance processing. When external data are received and local roll call continues to be unsuccessful, state S_3 is adopted.

State S_3 is usually of limited duration also since it is a state leading up to S_4 in the case of a new target that is being handed off for surveillance to the local sensor or in the case of a temporary loss of local reports due to fade. Such situations are normally quickly resolved by the re-interrogation, overcoming the interference, or by the re-orientation of the aircraft after a certain time. State S_2 is generally shortlived too, since the sensor transfers all-call acquisition to roll call (S_4) as soon as feasible. State S_4 corresponds to the normal track condition of successful roll call.

A track state transition check then consists of formulating the new state based on the reply type associated with the new report and on the coast counter

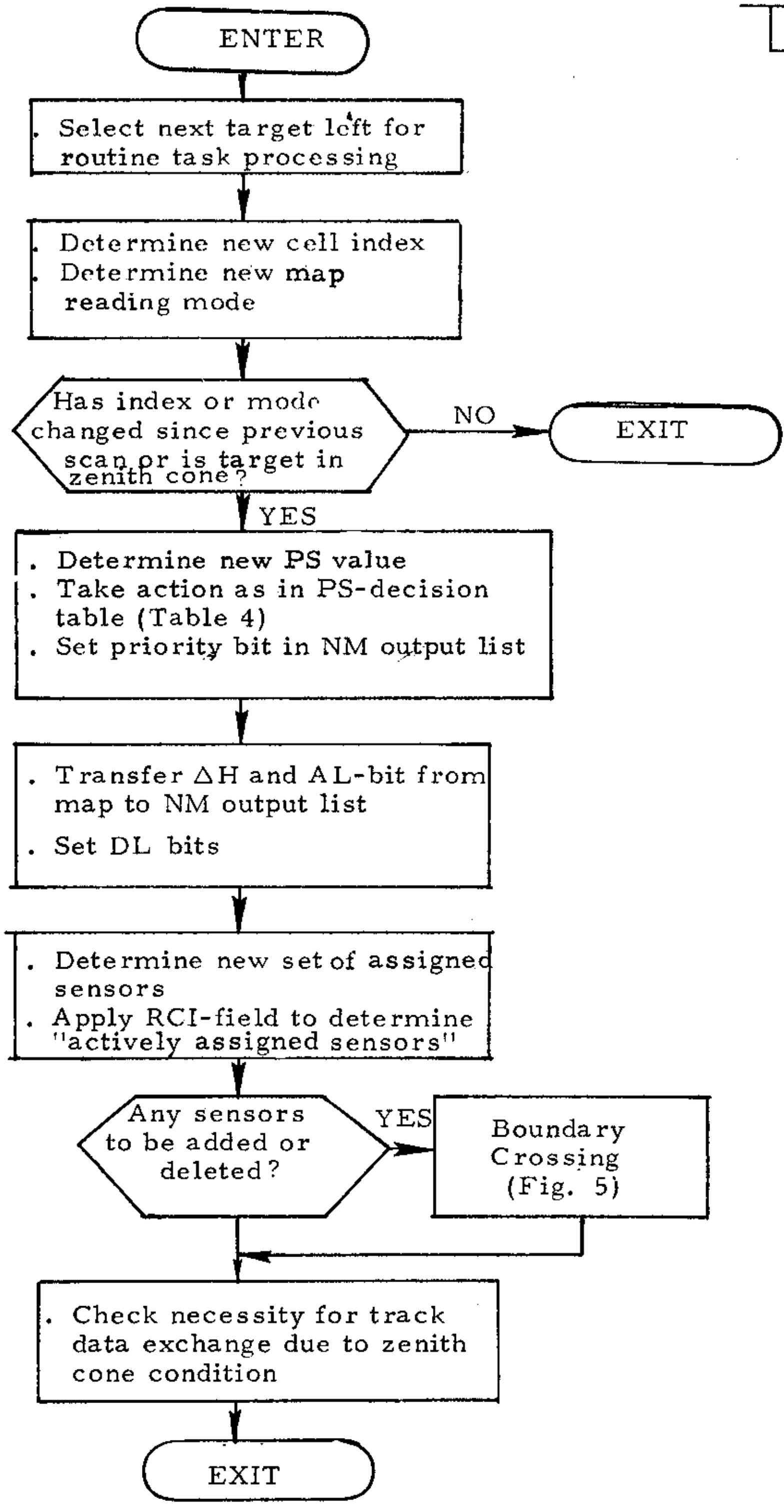

Fig. 3. Checks for boundary crossings and related tasks.

and comparing it with the previous track state stored in the track status list of the surveillance file. If any state transition occurred, this event triggers activity described in detail in subsection 6.2. The possible state transitions are illustrated in Fig. 4.

6.1.4 Other Routine Network Management Tasks

The out list is serviced routinely for all targets in the given azimuth sector by issuing a track data message to the sensors listed there unless a data start had already been issued this scan. When activity has been suspended on the outlist (OSE set), it must be determined whether or not that entry should be erased altogether. The criterion is whether the number of scans during which activity was suspended has exceeded a given threshold value.

All the above routine tasks are performed by azimuth sectors some time after the targets are released by surveillance processing. This way every target is processed once a scan.

Every target in the duplicate address alert table (DAAT) is also processed once a scan but at a fixed time (e.g., when the azimuth sector containing north is being processed). The DAAT table contains the DABS address for which there are two distinct DABS targets. Since assignment of DABS address is unique, this situation can only occur as a result of an error in setting the code or of a transponder failure. When a sensor initiates a DABS track, a check is made to determine if a track with the same ID already exists. If it does exist and neither track is accountable as a false target reflection, then roll call on both targets is prohibited by the local as well as the adjacent sensors. This is accomplished by dropping the tracks from the local surveillance file, creating an entry in the DAAT table and sending track alert messages to all adjacent sensors. An entry in the DAAT table contains the following information:

DABS ID	Active Flag ACF	First position $range_1, az_1$	First Counter	Second pos. $range_2, az_2$	Second Counter
24 bits	1 bit	30 bits	3 bits	30 bits	3 bits

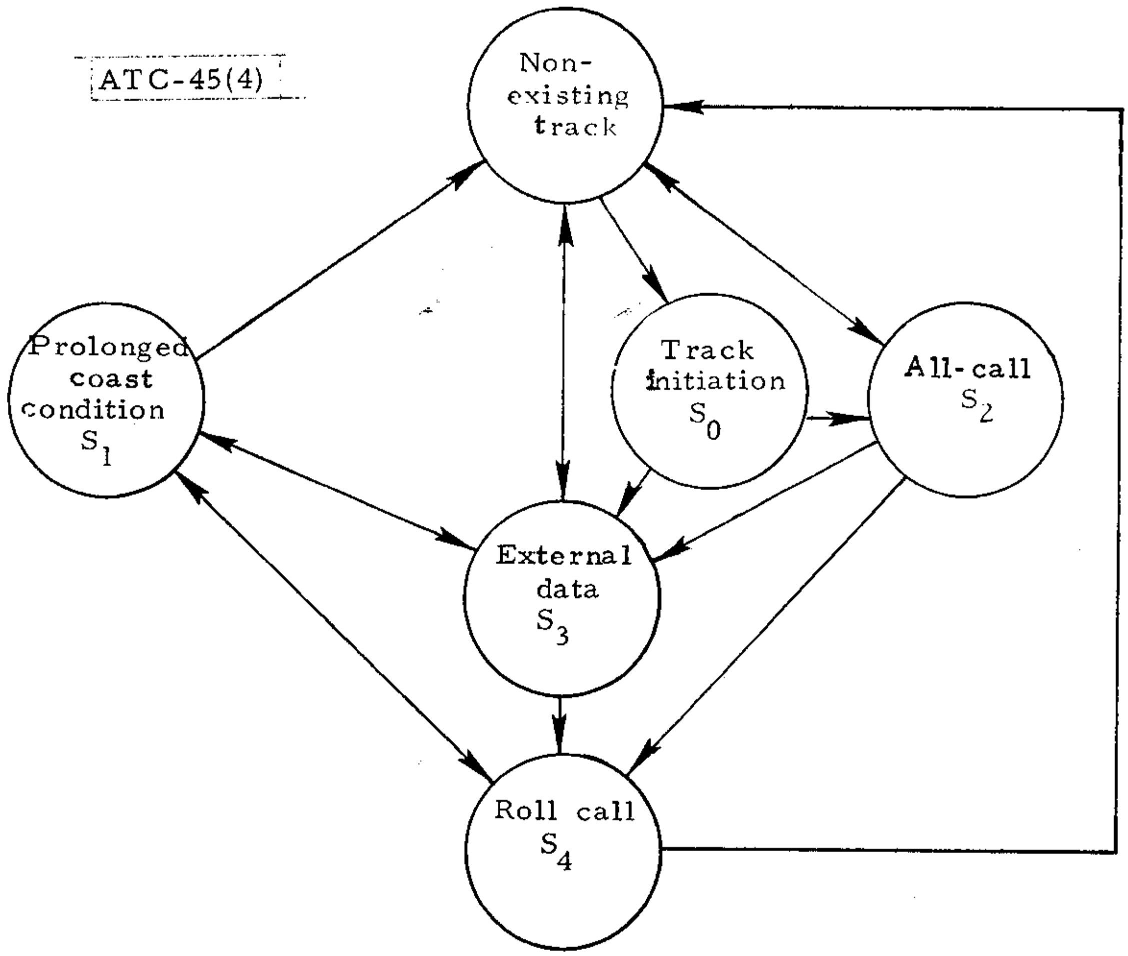

Fig. 4. Track status transition diagram.

Dropping the tracks results in both aircraft reverting to the all-call mode where they will remain until the duplicate address situation clears (e. g., one aircraft lands). Continued all-call interrogation serves the purpose of alerting the pilots to an abnormal situation since they both will receive an indication of loss of DABS contact (contact indication corresponds to receipt of regular discrete address interrogations). The mechanism of keeping track of the two targets is illustrated in Fig. 5. The active sensor is the sensor seeing both targets. It is responsible for disseminating the track alert message which keeps the entry for the DABS ID active at adjacent sensors which can see only one of the targets. A track alert message of a different format is also sent to all connected ATC facilities.

At a fixed time, once a scan, a northmark message reporting the time of the passing of true north by the antenna boresight, is disseminated to all connected sensors. This message is used by channel management for special modes of ATCRBS interrogation scheduling.

6.2 Special Event Tasks

This section describes in more detail network management tasks associated with special target related events, such as the target crossing a surveillance boundary or the track status changing, for example, from tracking on external data to tracking on local data.

6.2.1 Surveillance Boundary Crossings

When the routine tasks described in Section 6.1 have detected a change in surveillance assignment, the action will depend on the specific nature of the change. The coverage map will allow only certain types of transitions to occur between sets of assigned sensors with at most one new sensor added and one deleted at a time.

The changes meaningful to our design of the network management function are (a) addition of a remote sensor to the list of assigned sensors, (b) deletion of a remote sensor from the list, (c) deletion of the local sensor, (d) deletion of one remote sensor and the simultaneous addition of a remote

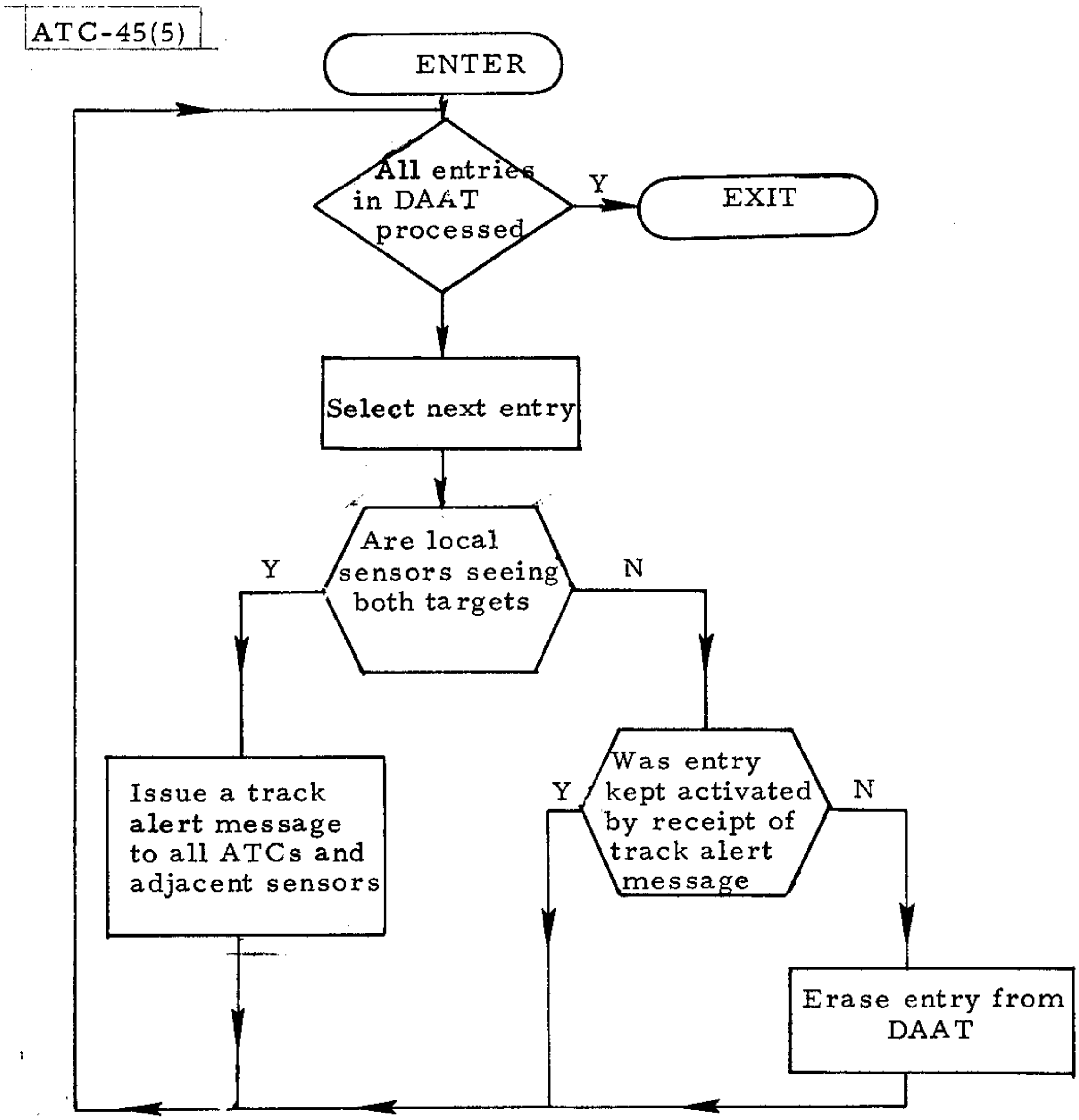

Fig. 5. Routine task of processing DAAT entries.

sensor, and (e) deletion of the local sensor and the simultaneous addition of a remote sensor.

In general, addition of a sensor to the set of assigned sensors causes a data start message to be issued to that sensor if the local sensor is capable of doing so. It also causes the sensor ID to be written in the out list (with the suspension flag OSE set equal to zero or one depending on whether or not the local track state is S_4). The new set of assigned sensors is written in the track status list of the track record of the DABS target except in a special circumstance resulting from adjacent sensor failure/recovery procedures (see subsection 6.3).

When a previously assigned sensor is no longer assigned, action depends on whether that sensor is the local or a remote sensor, on how many other sensors remain assigned, and on whether the sensor to be deleted is providing track data to another sensor.

When a remote sensor is no longer assigned and it was not currently receiving requested track data from the local sensor, the sensor ID is removed from all network management lists. If the remote sensor had been receiving track data it did not request, a data stop message is also issued to that sensor. If the local sensor is receiving track data from that remote sensor, a cancel request message is issued. However, if the remote sensor is receiving track data that it had requested, that remote sensor remains assigned and no action is taken.

When the local sensor is no longer assigned for a given coverage cell, the track record is erased except in the following cases:

(a) The local sensor is providing track data to adjacent sensors.

(b) The local sensor was previously the only assigned sensor. In this case a data start is issued to the new sensor before deletion is considered.

In either case the local sensor does not delete the track until a cancel request is received from all sensors currently receiving track data. When the local sensor deletes itself it must check if it is holding primary status. If so, it must first handoff primary status to the other assigned sensor. Figure 6 summarizes the activity associated with a boundary crossing.

6.2.2 Track Status Transitions

When the routine tasks described in subsection 6.1 have detected a track status transition, the action taken depends on precisely which transition occurred.

If the previous status value or state was S_1, it means that the sensor has issued a request for external track data. If the new state is S_3, this is the expected response and no action is needed. If the new state is S_4 and no other need for track data exists, the request should be withdrawn (request bit TR in the target status list of the surveillance file reset to zero) and a cancel request issued to all other assigned sensors recorded in the target status list. At the same time a data link capability message is sent to all connected ATC facilities now that normal roll call activity on the DABS target has been resumed. If the new state is S_2, no action is taken.

The other need for track data referred to above is a continued request from IPC or the need for standby data in anticipation of a fade in the zenith cone. If such continued need for data exists even when the track state is S_4, no request for cancellation of track data is issued. However, if the sensor recovering from a fade is primary, a cancel request message will in this circumstance be issued for the sole purpose of canceling the handoff of primary status but not with the intent of canceling the track data flow. (See subsection 6.4 also.)

If the previous value was S_2 (all call mode) and the new state is S_4, a data start message is issued to the other assigned sensors (if any) and correspondingly an entry is created in the out list of the DABS target. A data link capability message is issued to all connect ATC facilities.

If the previous state was S_3 and the new state is S_4, the request bit TR in the target status list is set to zero, and if IPC is not requesting external data on this target a cancel request message is issued to the sensors on the in list. If the sensor priority status PS was secondary temporary (S_T), the temporary handoff indicator field is also set in that message. In this case,

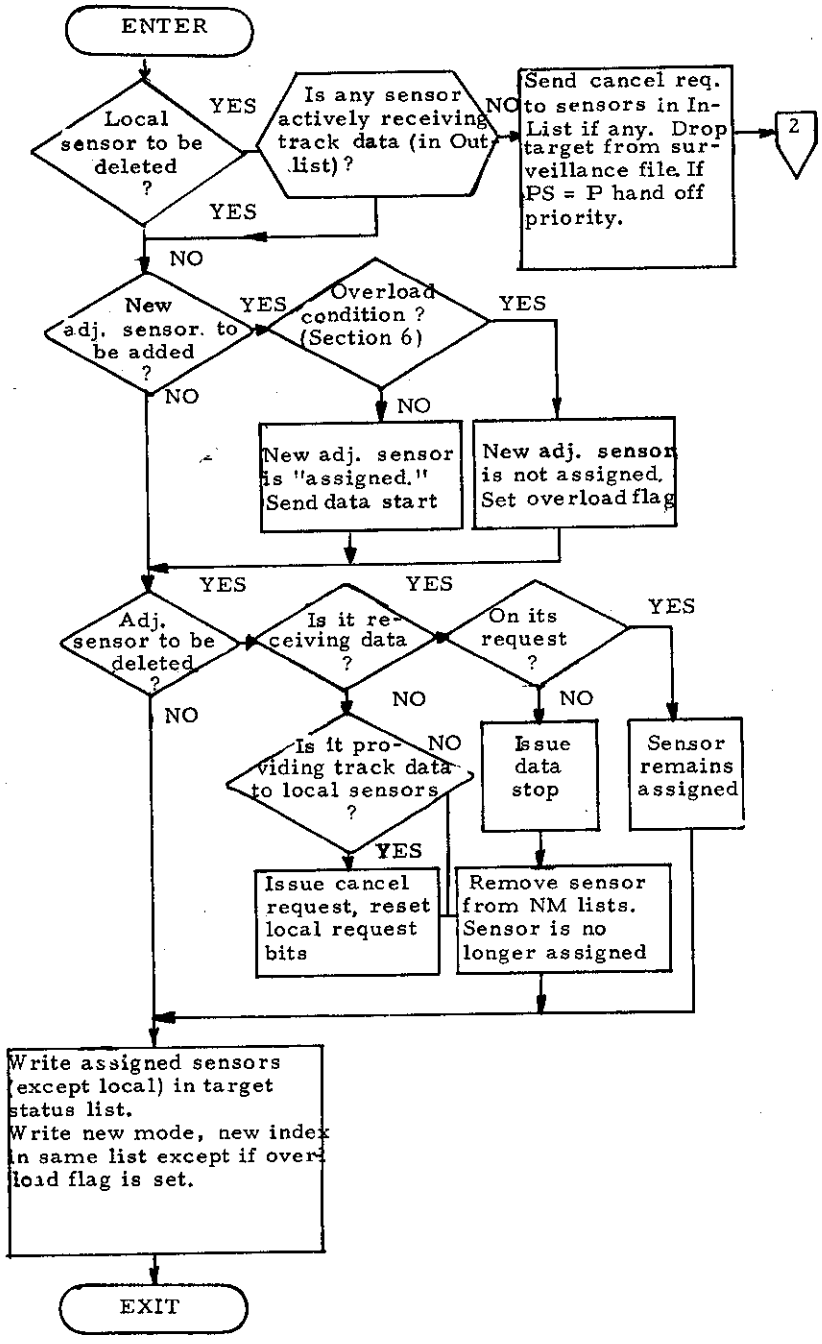

Fig. 6. Processing a boundry crossing.

the PS value reverts to P (see subsection 6.4 for details). If the new state is S_1, no action occurs.

If the previous state was S_4 and the new state S_1 (due to a missed scan), entries in the out list are flagged (OSE set) to temporarily suspend activity on this entry and a data stop issued to the sensors. At the same time a data request message is issued to all active assigned sensors not presently in the out list. The primary handoff indicator field is set in the data request message sent to the sensor with highest priority among the active assigned sensors if the local sensor is primary. In normal circumstances of dual coverage, there will be only one other assigned sensor, thus simplifying the choice.

State transitions that are not described require no special activity. Figure 7 summarizes the activity associated with track status transitions.

6.3 Sensor Failure and Recovery

When the performance monitoring function declares the failure of an adjacent sensor, the local sensor is assigned coverage over part of the area which was covered by the failed sensor. This is accomplished by adopting the "special mode" for reading the coverage map. Simultaneously, the coverage for ATCRBS/radar is increased by adjusting the ATCRBS/radar range mask used by surveillance processing and channel management (see subsection 7.2). In special circumstances DABS targets in the newly acquired area must be unlocked. This occurs when the failure of the adjacent sensor has not been established based on a "failure status message," but had to be inferred from the fact that ground communications were suddenly lost. If an "inferred failure" were declared for a sensor which had IPC responsibility (as indicated by field 11 of the cell content of the coverage map), then all DABS targets in these cells must be unlocked. The purpose of this unlocking is to prevent a DABS target from penetrating the IPC area of an adjacent sensor, which may still be functioning normally.

When a sensor recovers, its first message will be an OK status message to all adjacent sensors. At that moment all adjacent sensors adopt the "normal mode" for reading their coverage map. This will appear as a boundary transition for all targets in the cells affected by the mode change.

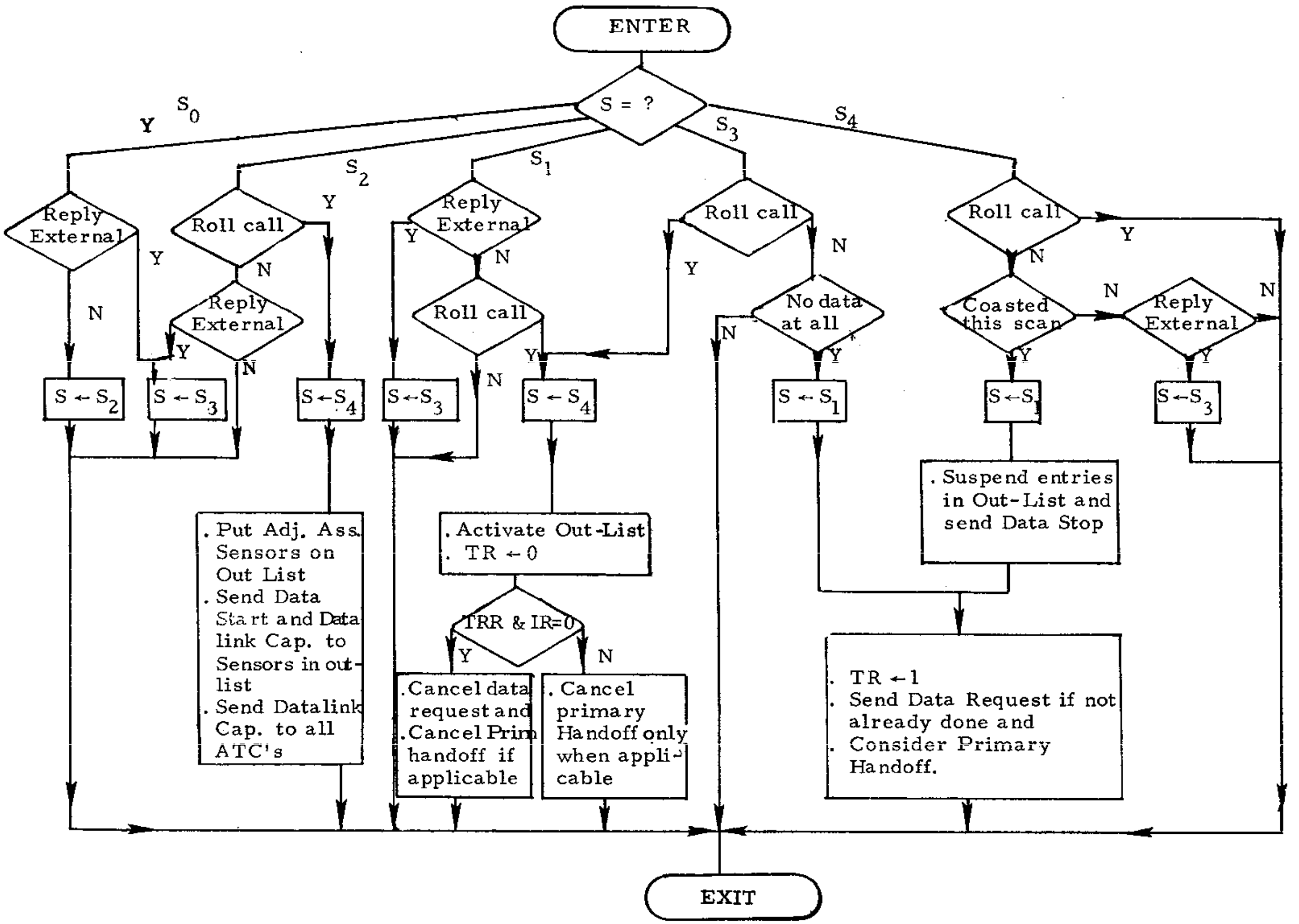

Fig. 7. Processing track status transitions.

For all these targets, a data start message must be sent to the newly recovered sensor. The number of targets could possibly be so large that the resulting number of messages causes a communications overload condition. The number of data start messages will therefore be limited to a number compatible with a "communications buffer full" condition. For the targets for which a data start was issued, a track data message will be issued every scan until the recovered sensor has successfully established the track and has issued a cancel request. For targets for which no data start could be delivered (due to overload), the new mode and the new set of assigned sensors are not written in the target status list. The routine tasks checking for boundary transitions (subsection 6.1) will therefore keep redetecting the need for a data start until that message is successfully issued.

When a sensor recovers and reacquires its normal target load via data starts from surrounding adjacent sensors, it also reestablishes its priority status PS over each target on an individual basis. It uses the decision tables described in the next paragraph.

6.4 Determination of the Sensor Priority Status

6.4.1 The Sensor Priority Status as a Decision Variable

The sensor priority status (symbol PS) is a parameter in the data block of each target in the surveillance file. This parameter acts as a decision variable for channel management and data link processing to perform or not to perform such tasks as providing synchro interrogations, ALEC service, and the service of downlinking pilot originated air-to-ground messages for the case where the maximum number of assigned sensors (MNAS) is at least two, i.e., the system uses at least dual coverage where possible. It is clear that a decision mechanism to determine sensor priority status in a system allowing only single coverage has little significance except in overlap areas.

The several values of PS reflect a priority of the local sensor over adjacent sensors to provide the above services for a given DABS target. The values are P (primary), S (secondary), P_T (temporary primary), S_T (temporary secondary), and N (neutral). Values P and S are the ones most commonly assumed. For a target on normal roll call they coincide with the sensor assignments of primary or secondary on the coverage map for the given target position. Values P_T and S_T, on the contrary, are temporary deviations from assignments on the map. These values are assumed in abnormal tracking conditions, when the sensor assigned primary by the map is unsuccessful in roll calling the target. Values P_T, S_T, and N may be assumed as well for targets in certain narrow zones called transition zones described below.

The channel management and data link processing tasks mentioned correlate with the PS values as follows: ALEC and synchro services are provided if PS $\neq$ S; downlink service is provided if PS = P or P_T.

The main reason for the introduction of the decision table determining PS, is to make sure that no two sensors have PS = P or P_T for the same target at the same time. It may be shown that, with the DABS data link protocol, such dual primary assignment may cause loss of downlink messages.

6.4.2 Areas of Dual Primary Assignment in the Coverage Map

If the PS values were to coincide with the primary/secondary assignments on the map, there would be areas where PS = P for two adjacent sensors. There are two reasons for the existence of such overlap areas. The first is that the coverage map approximates areas of primary/secondary assignment in terms of a number of integral cells while not allowing gaps where no sensor is assigned primary. Figure 8 shows how a boundary between areas of primary assignment is implemented in terms of the cells of two adjacent sensors.

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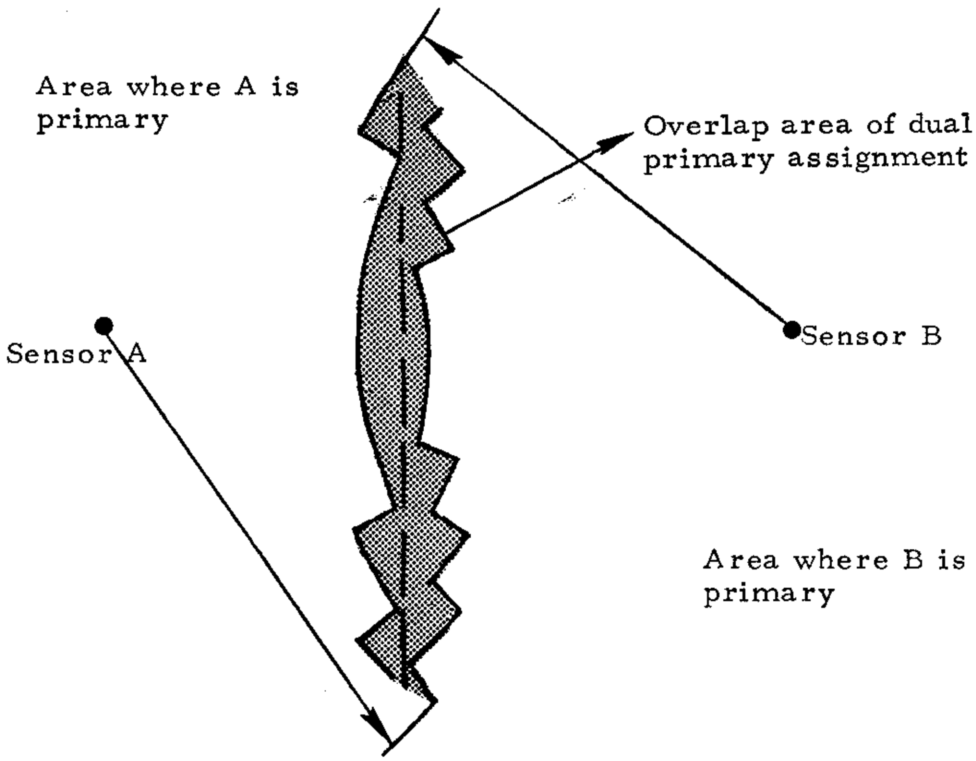


Fig. 8. Primary assignment in horizontal plane.

The reason for the incongruity is clearly the use of an (range, azimuth) oriented gridstructure that was dictated by other sensor requirements.

A second reason for the existence of and the need for overlap areas is the requirement to leave no gaps of primary assignment in the vertical dimension while using the map with the slant range and azimuth coordinates provided by surveillance processing. Figure 9 shows the overlap area of Fig. 8 in the vertical plane. Although no gaps in primary assignment exist in the horizontal plane, the use of slant range instead of ground range locates aircraft in vertical area II (zones of secondary assignment for A and B). The overlap zone has to be widened as shown in Fig. 10 in order to close this gap in primary assignment in the vertical dimension.

Overlap areas are the expression of incompatibility of coverage maps of adjacent sensors but as such are not visible on the map of one sensor. Since the dual assignment problem will have to be resolved by each sensor for targets in overlap areas, these areas have to be made part of the description of the map. This is done by imbedding the overlap areas in a zone made up of entire cells for each sensor. This zone will be referred to as the "transition" area of the map. It is a zone of transition between areas of primary and secondary assignment for the local sensor.

A target can thus be found to belong to the primary, secondary, or transition area of the map. These findings will constitute the map input to the sensor priority status decision table described next.

6.4.3 The Sensor Priority Status Decision Table

The purpose of the decision table is to make certain that one and only one sensor has a sensor priority status (PS) equal to primary (P or P_T) for each DABS target under all circumstances. Such unambiguous status assignment then means that at least one, but not more than one, sensor will handle downlink messages. Table 4 describes the decision table. The rows represent the present value of the sensor priority status PS. The columns represent inputs from the coverage map from adjacent sensors via messages, or from changes in track condition (successful roll call versus prolonged coast condition).

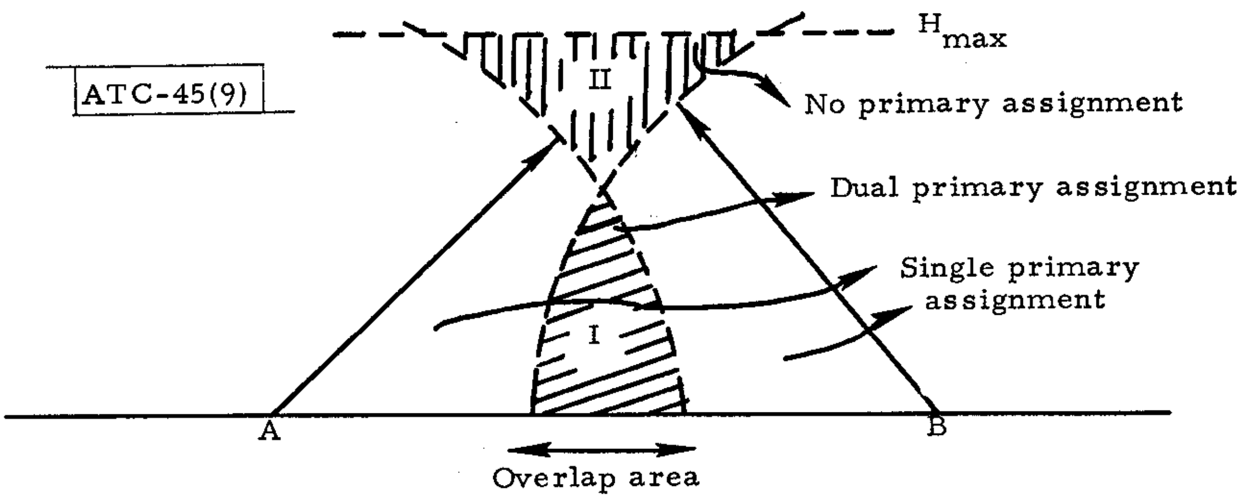


Fig. 9. Primary assignment in vertical plane.

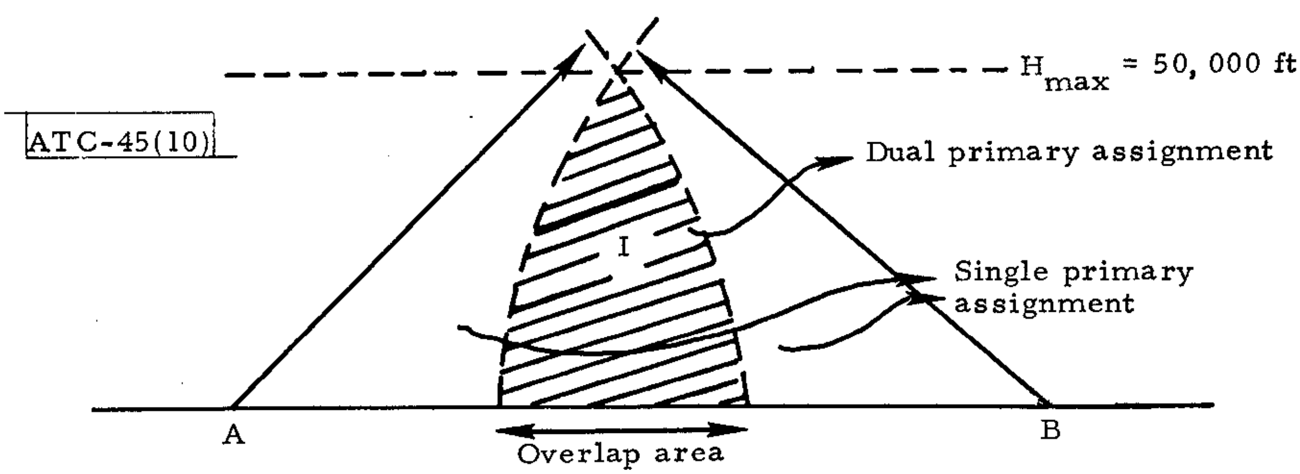


Fig. 10. Enlarged overlap area.

TABLE 4

PRIORITY STATUS DECISION TABLE

	Map Inputs			Permanent Handoff Message Received		Temporary Handoff				Messages Received		
						Message Received		Message Sent		Primary Assignment Request	Primary Assignment Approval (11)	Primary Assignment Disapproval (12)
	P	T	S	S	P	Start	Cancel	Start	Cancel			
P	P	P	S[1][4]	S	-	-(*)	-	S_T	-	P[10]	-	-
S_T	S_T	S_T	S[1][3]	S[3]	-	P(**)	-	-	P	-	-	-
P_T	P[2]	P_T	P_T	S	P	-	S	S(***)	-	-	-	-
S	P[2]	S	S	S	P	P_T	-	-	-	S[9]	-	-
N	P[5]	N[6]	S	-	-	-	-	-	-	P[8] S[7]	P	S

(1) Send permanent primary assignment to sensor that is primary for that cell (based on local map).

(2) Send permanent secondary assignment to sensors that are non-primary for that cell.

(3) Cancel temporary handoff if to a third sensor.

(4) This state change is conditioned on a B- or D-bit not being set (i. e., no downlink communication is in progress).

(5) Send a permanent secondary message to all other assigned sensors (while assuming primary assignment).

(6) Send primary assignment request (to both sensors if in triple transition zone).

(7) Send primary assignment approval if:

(a) Request not sent by this sensor or
(b) Request sent and this sensor not dominant.

(8) Send primary assignment disapproval if:

(a) Request sent by this sensor and
(b) This sensor is dominant.

(9) Send primary assignment approval.

(10) Send primary assignment disapproval.

(11) Approval from both sensors if in triple transition case.

(12) Disapproval from either sensor if in triple transition case.

(*) Applies to all error conditions: no state change.

(**) Occurs when adjacent sensor that accepted handoff loses contact with target and hands assignment back to original sensor. Handoff to a third sensor, if available, is tried.

(***) Occurs when local sensor that accepted handoff loses contact and hands the assignment back to original sensor.

The entry in the matrix represents the next status PS; the subscripts and stars in the same entry refer to additional action, or they are simply explanations.

Figure 11 presents the table in the form of a state transition diagram. Only the meaningful transitions are shown.

A temporary handoff is associated with a fade condition at the primary sensor. Under normal conditions the sensor experiencing a fade issues a data request at the beginning and a cancel request at the end of the fade. Whenever the sensor is primary (PS = P), it regulates handoff of priority status to the sensor numbered secondary on the coverage map by setting a special bit in these messages. The sensor receiving the handoff assumes priority status PS = P_T, if it is discretely tracking the target (track status S = S_4). If not it refuses the priority handoff while notifying the sensor it is unable to comply with the request for track data. This is done with a data stop message with a special bit set. Whenever the sensor which assumed PS = P_T experiences difficulty and can no longer comply, it will also issue a data stop and hand the priority status back to the original sensor.

The next section provides details on how to process network control messages coming from an adjacent sensor.

6.5 Handling of Network Control Messages From Adjacent Sensors

Once during the processing of each surveillance sector (nominally every 1/32 of the scan time), the buffer of incoming network control messages must be emptied and the appropriate action taken in response to the messages. The repertoire of messages and their functional significance were given in Section 5. The action taken is determined by the type code which is the first field in each message (for message formats see Appendix B).

6.5.1 Action for the Data Start Message

If the DABS target referred to in the message is unknown to the local sensor, a new entry is created in the surveillance file. All the information carried in the data start message is written into that entry: position and

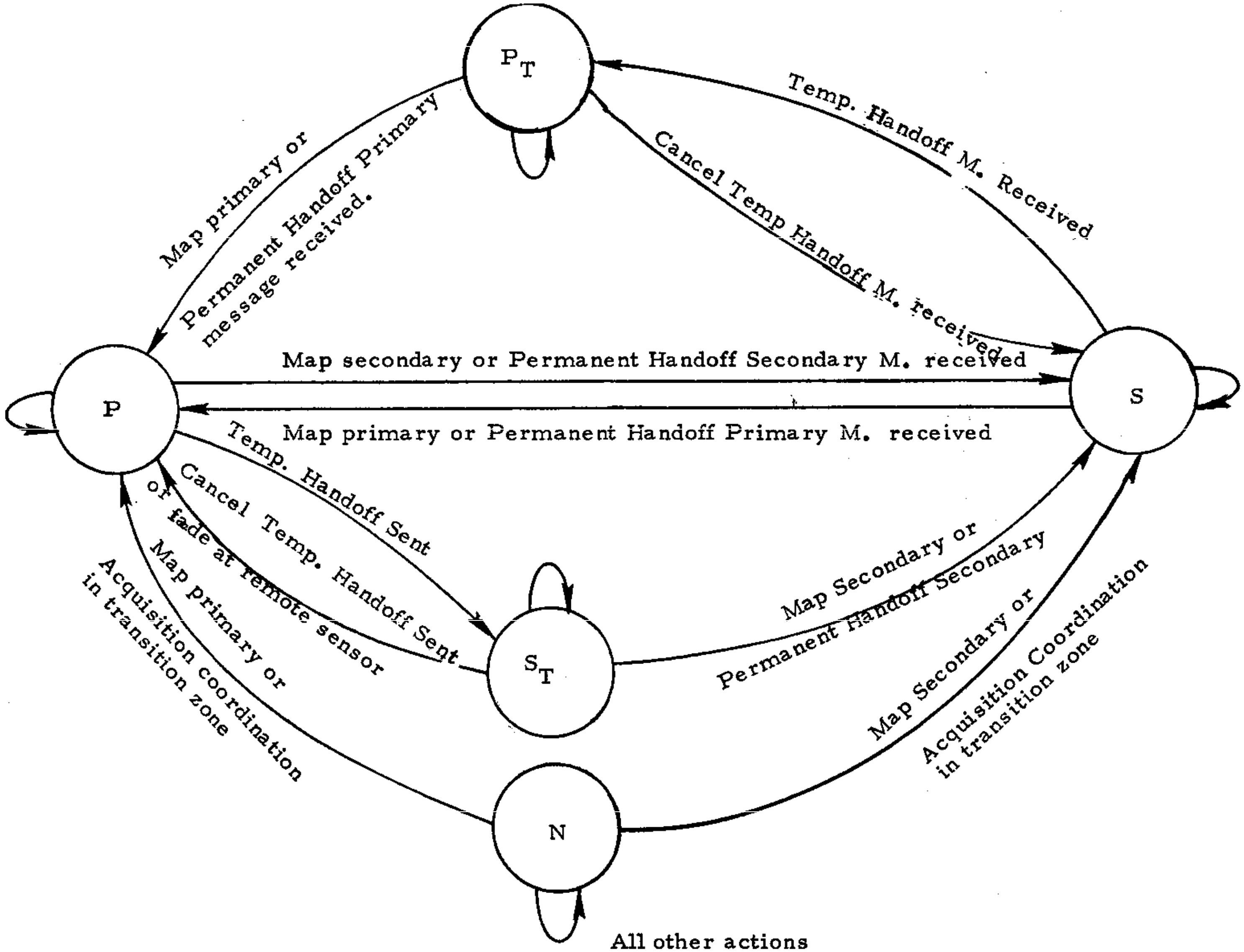


Fig. 11. State transition diagram for single primary management.

velocity (after time adjustment, using the time reference in the message, and after coordinate conversion, using the sender ID), transponder capability, roll call inhibit flag, and sender ID. The track status in this case will be given the value S_3.

If an entry for the target already exists in the local surveillance file, the further use made of the message depends on (a) whether or not the local sensor had requested external data, and if so (b) for what reason and, (c) whether or not another sensor is already providing track data to the local sensor on the same target. The tests are summarized in Fig. 12. The result is that either (a) the data is refused by issuing a cancel request message, or (b) the data is not refused at this time although not actually used, or (c) the data is used and integrated with the local track. In this case the same report (but not coordinate converted) is sent to the local IPC. The last possibility is (d) that the report is not wanted for local surveillance processing but was requested by IPC. It and all following track data messages are then sent to IPC.

If an entry does already exist in the local surveillance file, the possibility that the new data relates to a different DABS target with the same ID must be examined. The report is therefore subjected to a reasonableness test which checks whether the range difference and crossrange difference between reported and tracked range are nominally less than 5 nmi. In the exceptional circumstance that the test fails, the two targets involved are taken from roll call and further tracked on all-call. An entry is created in the duplicate address alert table (DAAT). Routinely for each entry in the table, a track alert message is disseminated (see subsection 6.1.4).

6.5.2 Action for the Track Data Message

First the external report is subjected to a reasonableness check. The normal case is that the report passes the test and is further handled in accordance with the setting of a series of flags. The destination is decided based on track status S and the IPC request bit. Figure 13 illustrates the logic.

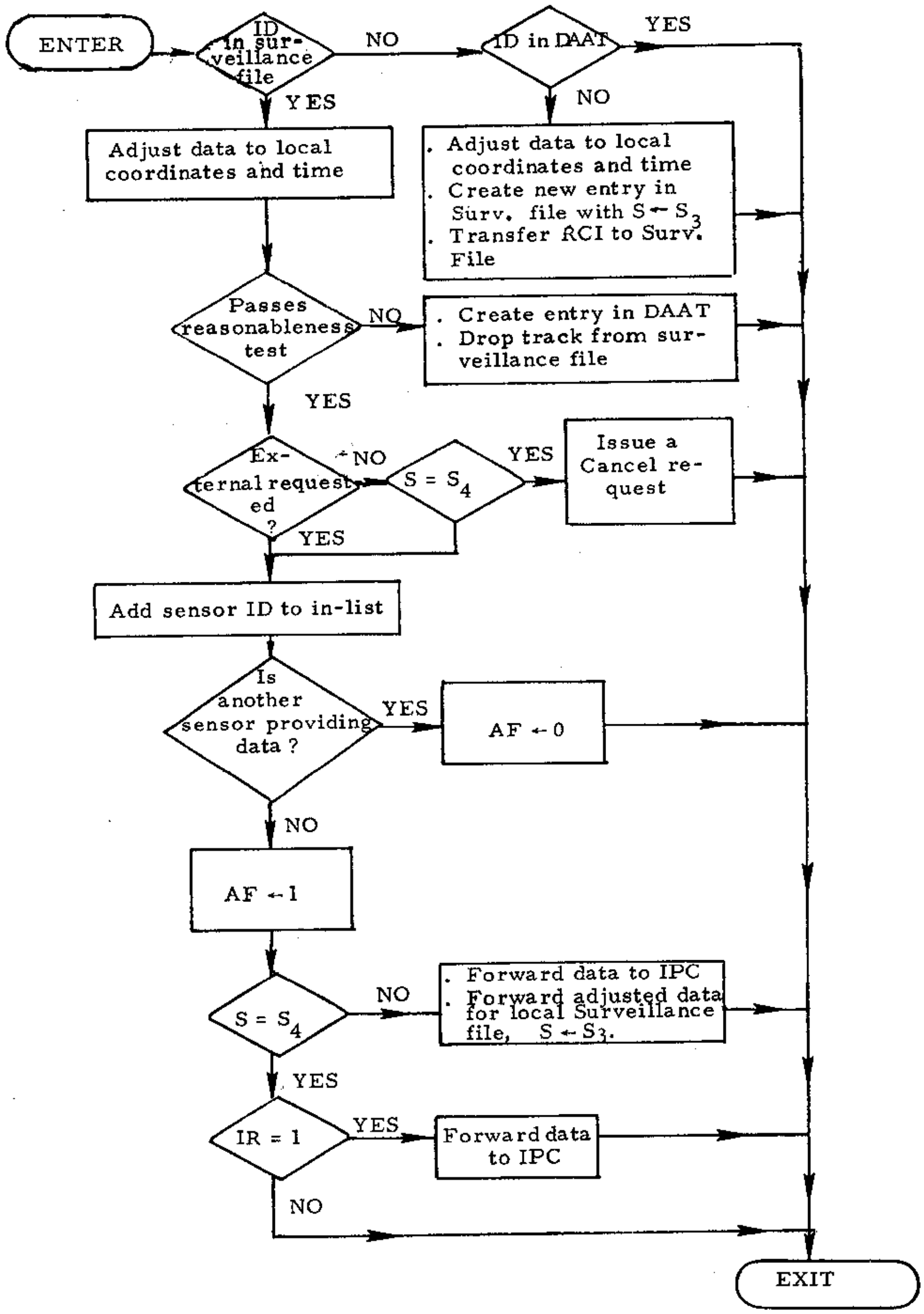


Fig. 12. Processing a data start message.

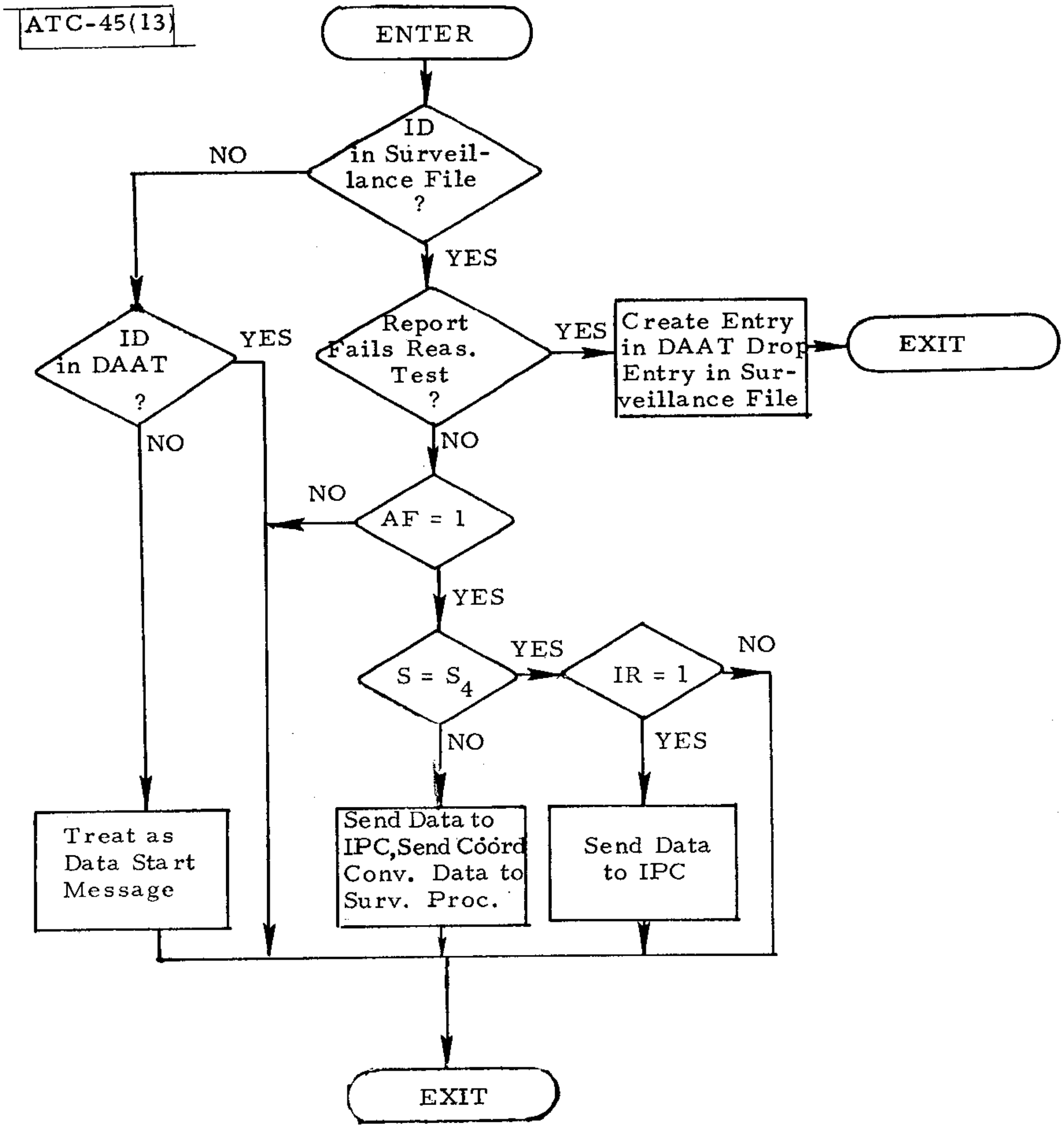


Fig. 13. Processing a track data message.

6.5.3 Action for the Data Request Message

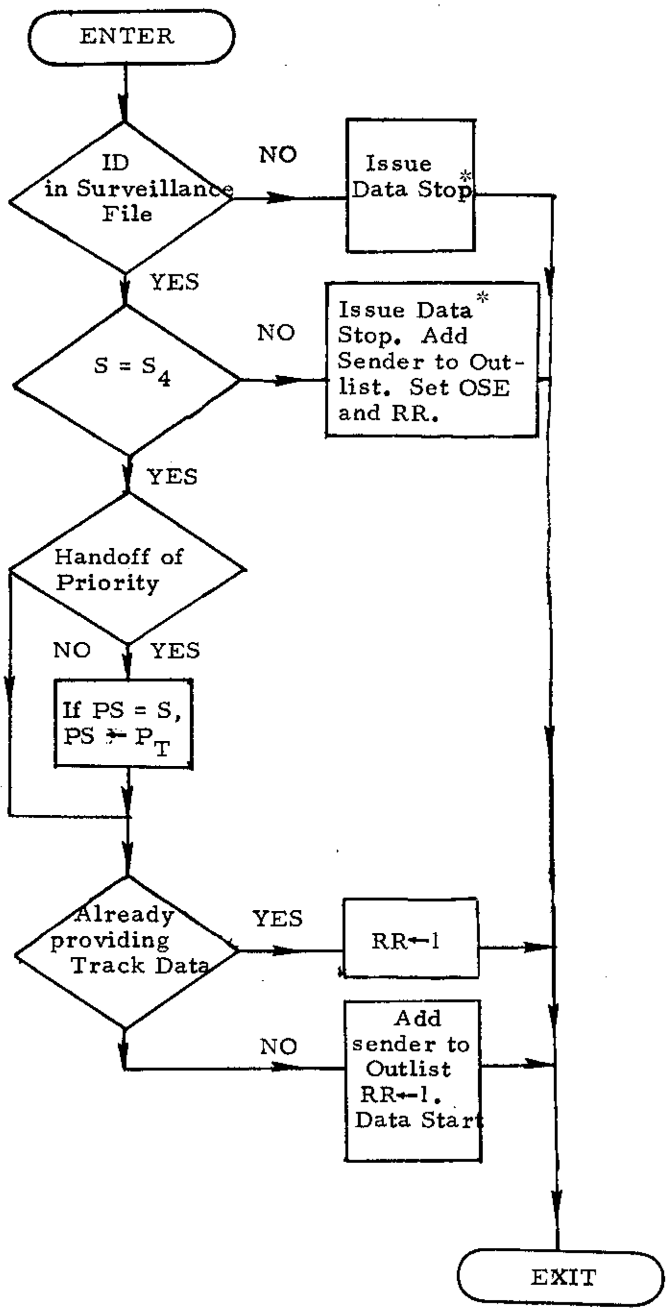
The data request message serves the dual purpose of requesting data and handing off priority status. If the sensor requesting assistance is primary and a fade occurs, this dual purpose is virtually always served. The exception is a case where a data request had previously been issued for other reasons than a fade (e. g., entrance in the zenith cone). In this case a data request may still be used for the sole purpose of handing off priority. The normal response to a data request is a data start if able to comply, a data stop if unable to comply, and no response if the sole purpose was to hand off priority. Whenever a data request is received, the sender ID becomes part of the out list (with OSE eventually set) until a cancel request is received. Figure 14 summarizes the processing of a data request message.

6.5.4 Action for the Cancel Request Message

The cancel request message is the complement of the data request message. It may cancel the data request or cancel a priority handoff or both. To distinguish between the several possibilities, two flags are used (see formats in Appendix B). The first flag indicates if the message signifies cancellation of priority handoff only, or if it signifies cancellation of the data request. In this latter case the second flag signals if it is, in addition, a cancellation of priority handoff. The response to cancellation of data request is to issue a data stop and erase the sensor ID from the out list. The response to cancellation of priority is to assume secondary status if the current status were temporary primary.

6.5.5 Action for the Data Stop Message

A data stop indicates that the flow of track data is ending either because the sender cannot provide the data or is complying with a cancel request. The action taken by the receiving sensor consists of erasing the sender ID and the associated AF flag from the in list if they are present. If another sensor is listed in the in list with flag AF = 0, that flag is reset to AF = 1. If the temporary handoff indicator bit is set in the data stop message, it means that



*Returning the priority handoff bit.

Fig. 14. Processing a data request message.

the sensor to which primary status was given is experiencing difficulties itself and thereby hands primary status back to the local sensor. The local sensor that had adopted status PS = S_T, reverts back to PS = P. If other sensors are assigned and the circumstances so require, it may try to handoff primary status to a third sensor.

6.5.6 Action for the Transition Zone Coordination Message

Whenever a target is acquired (and a new track started) in the transition zone of the coverage map, the priority status PS must be negotiated with the adjacent sensor sharing that zone.

A transition zone coordination message has a qualifier field (see Appendix B) which specifies whether this is (a) a request for primary assignment, or (b) a response to a request by the local sensor which is either a disapproval or an approval. At receipt of a request, a disapproval is issued when PS is P and in case PS = N when the local sensor had requested primary assignment first and is the dominant sensor. In all other cases the response is an approval. Dominance refers to a pre-established ordering among connected sensors for the purpose of breaking a tie in assignment of priority. When an approval or disapproval is received, the only action is to assume status PS = P or PS = S, respectively. The logic is summarized on Fig. 15.

6.5.7 Action for the Permanent Handoff Message

The qualifier field in the message will specify if this is a permanent handoff of primary or secondary status. The response is to adopt the specified status and issue an accept permanent handoff message with the qualifier field specifying the adopted status. In this case, if the feature of roll call inhibited sensors is in use, the sensor may want to signal the other sensor (while handing off primary status) that it will no longer provide data but instead requests data. This signaling is done via a special bit in the message.

6.5.8 Action for the Accept Permanent Hand Off

The priority status logic calls for the sensor initiating primary handoff to assume a status of permanent secondary at the same time that the

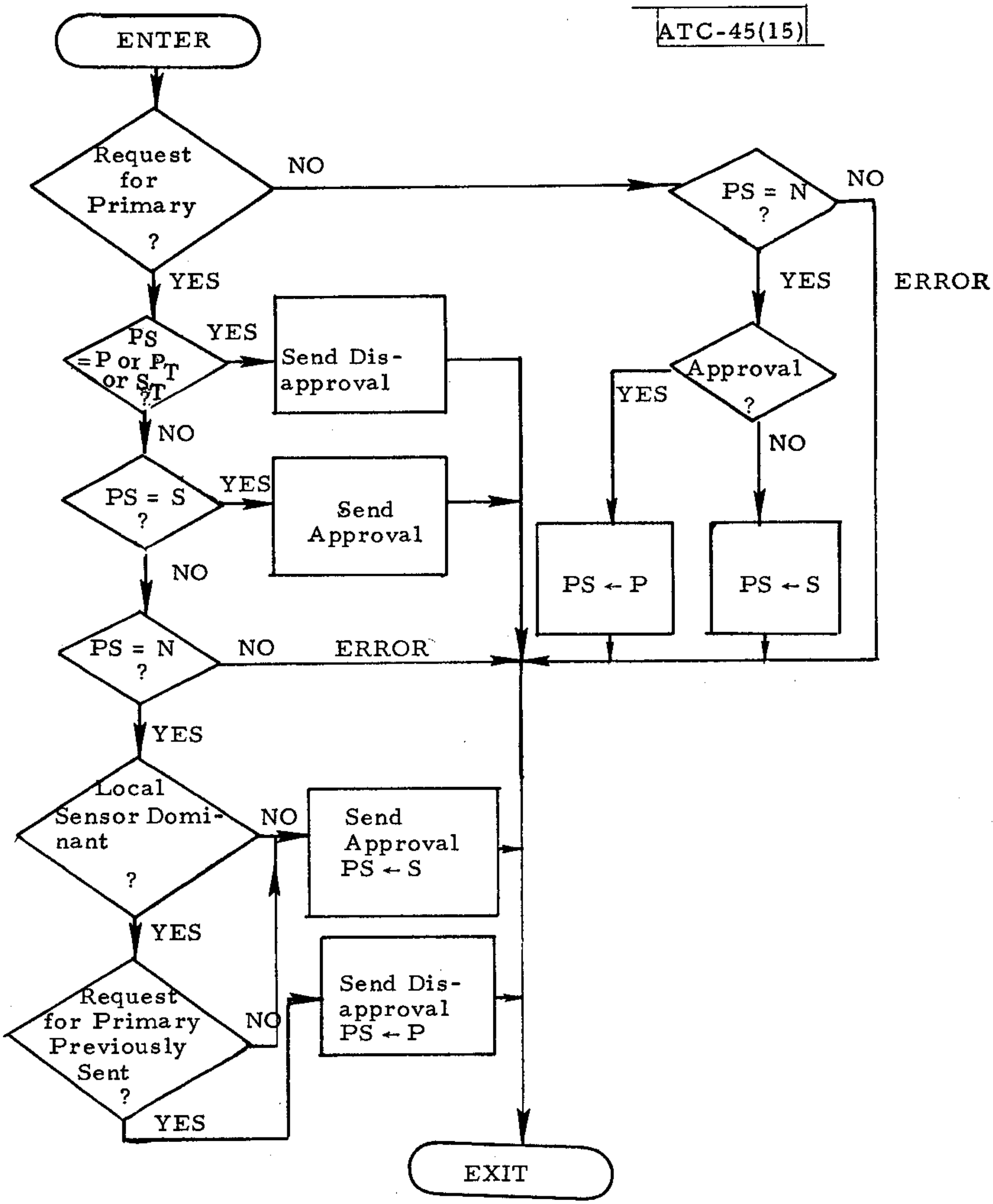


Fig. 15. Processing the transition zone coordination message.

permanent handoff message is sent. This means that during the time of transfer of the permanent handoff message, no sensor will have primary responsibility for the referenced aircraft. This strategy is required for the downlink message protocol since it never permits more than one primary sensor to be primary, even during handoff. A different approach is required to serve the needs of IPC. The IPC function uses the primary sensor to deliver its PWI and command messages. As before, single primary sensor assignment is required in steady state. However, during handoff no break in message delivery service can be permitted.

This effect is provided by a flag provided to IPC called the permanent handoff in progress (PHP) flag. PHP is set when a sensor performs handoff, and reset when the accept permanent handoff message is received. IPC will use a sensor to deliver its messages if the sensor is assigned primary or if its PHP flag is set. In this way, a small overlap period occurs where two sensors may be used for message delivery (namely when the accept is underway).

6.5.9 Action for the Track Alert Message

The sole purpose of dissemination of track alert messages is to alert adjacent sensors to the presence of two targets with the same DABS-ID. This causes the targets to be placed (or kept) in the DAAT table and prohibits them from being roll called. An entry in the DAAT table at a sensor seeing only one of the offending targets is erased if no track alert message is received for one scan.

6.5.10 Action for the Request/Cancellation of Request for Data from IPC

The action taken is to set or reset bit IR in the track status list and data request/cancel request for data from other assigned sensors. If at the time IPC requests data, data are already forthcoming or have been requested for other reasons, then clearly no new data request message needs to be issued. The setting of the IR bit serves to record the reason for the request for external data and is used in the routing of external data to the intended user.

SECTION 7

7.0 NETWORK MANAGEMENT FOR ATCRBS TARGETS

7.1 Track Data Exchange on ATCRBS Targets

The DABS network allows for track data exchange between sensors on ATCRBS targets having Mode C capability. The main purpose of this data exchange is to maintain track continuity through fades and to provide backup data to IPC for targets in a potential conflict situation. The mechanism is much the same as for DABS targets. On a scan by scan basis the track position and status S are examined in order to detect fade conditions or entrance in the local zenith cone. Requests by IPC are processed as they are received. When any such condition triggers a request for external data, an ATCRBS data request message is issued and one of three request bits (TR, TRR, or IR) is set in the surveillance file. When external data are no longer needed (none of the three bits is still set), an ATCRBS cancel request is issued. The messages for ATCRBS targets contain the ATCRBS code and the track number of the target at the requesting sensor. This eliminates the need for a correlation decision when track data are received. When a sensor receives an ATCRBS data request, it will search through its surveillance file to identify the corresponding track based on a simple association check.

For a 4096-code ATCRBS target, the check consists of matching the code against the lists of 4096-ATCRBS codes tracked by the local sensor. If several tracks with matching code are found, the unique track, which lies within ADIS of the (coordinate converted) position of the target referenced in the ATCRBS data request message, is selected. ADIS is nominally equal to 2.5 nmi.

For a nondiscrete ATCRBS target, the association check is based on position first and then on code. The sector most probably containing the target is identified based on the (coordinate converted) azimuth. This sector, plus the preceding and the following sectors are searched on code. The unique track within a distance ADIS of the target position in the message is selected.

If no track or several tracks were found to satisfy the association check, no choice is made and an ATCRBS data stop message is issued to signal inability to comply with the request.

Unlike DABS, no handoff is needed for ATCRBS targets when it crosses a surveillance boundary. This limits track data exchange to the cases discussed above.

7.2 DABS Compatible Coverage Areas for ATCRBS/Radar

The local sensor only acquires reports on ATCRBS target and radar targets in the area for which it is actively interrogating DABS targets, i.e., where the sensor is "assigned" and is not roll call inhibited.

This is accomplished for aircraft answering DABS all-call and ATCRBS interrogations by adjusting the listening time after these interrogations as a function of azimuth. An area mask, outlining the DABS active required area, is also applied to radar reports; only those radar reports within this area will be retained. In both cases, use is made of a lookup table called the ATCRBS/radar range mask. The table, 64 entries long, specifies the maximum range of interest for each $5\frac{5}{8}$ degree-wedge.

The area where a sensor is actively assigned, changes with the mode in which the map is used. The active required zone and hence the ATCRBS/radar range mask corresponding to it (used under normal operating conditions) are part of the general map description. That mask table will be termed standard. For operating conditions during an adjacent sensor failure, the standard active required zone (and the mask) is enlarged in an attempt to maintain a constant multiplicity of coverage over the total area for which the DABS network is responsible. This enlargement is accomplished by reading the sensors from the coverage map in the special mode. As soon as the performance monitoring function declares the failure mode for an adjacent sensor, this special mode is adopted and a new mask table is set up by the routine described below. This mask table is then used as long as the failure persists. The standard mask table is reinstated when normal operations resume.

The routine used to set up the new mask table consists of establishing the range of the (enlarged) active required zone of the local sensor for each of the 64 azimuth wedges. To do this, the maximum cell range for the given wedge must be read for which the local sensor is among the MNAS first sensors (ignoring the failed sensor(s)) listed in the coverage map and is not roll call inhibited. The outer range of that cell is the value entered in the mask table for the given azimuth wedge.

SECTION 8

8.0 THE INTERFACE OF THE SENSOR WITH THE NETWORK

The sensor communicates with the external users through an interface. The interface feeds a series of one-way channels for surveillance data to ATC facilities and a series of full duplex channels for communications data. The communications channels divide into two groups: one handling communications with ATC facilities, and the other handling the communications with other sensors (and IPCs) within the DABS network. A channel between the local sensor and the ATC facility or adjacent sensors may consist of several parallel links to support a particular data rate.

The surveillance and communications interface between the sensor and ATC facilities is described in detail in Report FAA-RD-74-63 entitled "Provisional Message Formats for the DABS/NAS Interface" [Ref. 2].

The interface between sensors and, specifically the flow of messages through that interface to particular functions within the sensor, are the topics of this section.

8.1 The Sensor/Sensor Interface

The communications data link between sensors is a two-way channel with a capacity of 7000 BPS. Signal formats and interface procedures will conform to the usage of the Common ICAO Data Interchange Network (CIDIN) as specified by the Automated Data Interchange Systems Panel (ADISP) [Ref. 3], for a balanced point to point configuration of two stations.

To transmit messages over the channel, they must be "packaged" by the interface into a certain format called a frame. Transmission itself is subject to a specified set of procedures. The details of the frame format and the transmission protocol are the same as for the sensor to ATC communications interface [Ref. 2]. The message itself is called the link data field of the frame. The formats of the messages related to network management are described in Appendix B.

8.2 Message Routing

Messages received by the sensor through the interface must be routed to the appropriate function in the sensor, and a response formulated when the message is not acceptable. These tasks are performed by the message routing function.

Messages from local sensor functions to the interface are not handled by message routing since they can be placed directly into the appropriate output buffer by the originator of the message. The major sensor functions originating and receiving messages are performance monitoring, data link management, network management, surveillance processing, and the local IPC function.

These functions, except IPC, receive all their messages from external sources through message routing. IPC, in addition to receiving messages from message routing, has a direct link to the sensor interface for ATC and adjacent IPC messages. Figures 16a and b illustrate the message flow between the interface and the local sensor functions. Although IPC may appear to be a local sensor function, it interacts with the local sensor as a separate entity. The message flow between IPC and the local sensor functions is considered in Section 9.

8.2.1 Identification of the Message Flow

All messages except surveillance reports are identified by an 8-bit type code. The first four bits are a prefix identifying a class of messages which are logically similar. The classes relevant to sensor to ATC communications are described in Reference 2. Only the subset of messages handled by message routing is listed here with their class, name and type code (Table 5). Figure 17 illustrates the flow of messages through message routing by identifying their prefix on the arrows shown. Messages corresponding to a flow of information listed in Tables 6 and 7, mostly bypassing message routing, are placed directly in the appropriate output buffer by the sensor

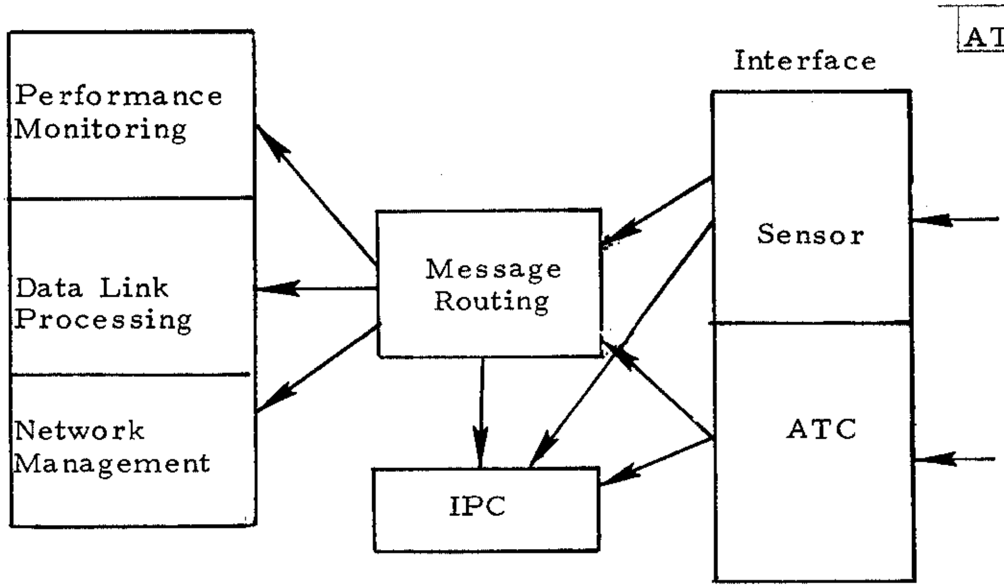


Fig. 16a. Message flow to local sensor functions.

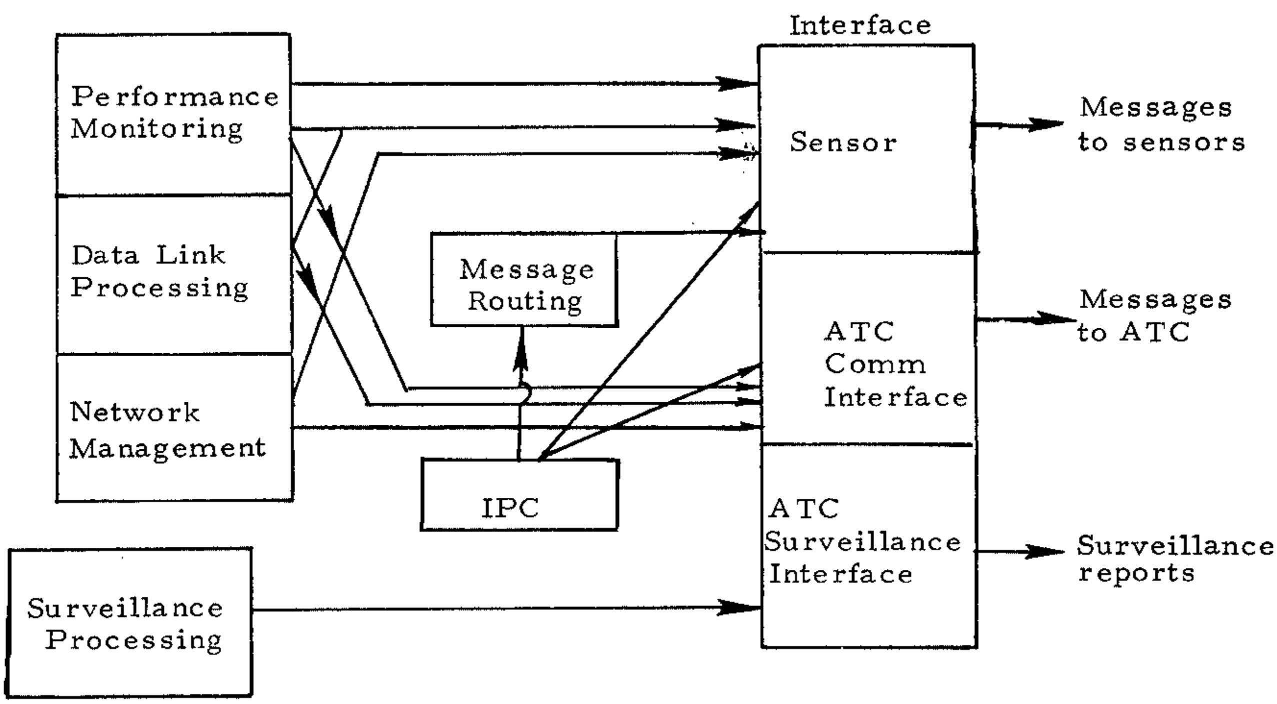


Fig. 16b. Message flow from local sensor functions to the interface.

TABLE 5

MESSAGES HANDLED BY MESSAGE ROUTING

(a) NAS to DABS Uplink Messages			
1	0010	0001	Tactical uplink message (to a DABS aircraft)
2	0010	0010	ELM uplink message (to a DABS aircraft)
3	0010	0011	Request for downlink data (from a DABS aircraft)
4	0010	0100	ATCRBS-ID request (to a DABS aircraft)
5	0010	0101	Uplink message cancellation request (of a previous message)
(b) NAS to DABS Status/Control Messages			
6	0110	0001	Test messages (to a DABS sensor)
7	0110	0010	Test response message (to a DABS sensor)
8	1001	1011	Altimeter correction message (to a DABS sensor to replace the altitude correction list of the coverage map)
9	1001	1001	ATC failure/recovery message
10	1001	1010	All radar data request message
(c) IPC to Local Sensor Messages			
11	1010	0001	Uplink message (monolink)
12	1010	0010	Uplink message cancellation request (monolink)
13	1010	0011	Request for downlink data (monolink)
14	0111	0100	IPC status (to local performance monitoring function)
15	1001	1000	Track data request/cancel message (to local network management function)
16	1011	0001	Uplink message (multilink)
17	1011	0010	Uplink message cancellation request (multilink)
18	1011	0011	Request for downlink data (multilink)

TABLE 5 (continued)

(d) Remote Sensor to Local IPC Messages			
19	0011	0001	Message rejection/delay notice
20	0011	0010	Uplink delivery notice
21	0100	0011	Pilot acknowledgment
22	0100	0001	Tactical downlink (comm B)
(e) Sensor to Sensor Network Control Messages			
23	1001	0001	Data start
24	1001	0010	Data stop
25	1001	0011	Data request
26	1001	0100	Track data
27	1001	0101	Cancel request
28	1001	0110	Permanent handoff
29	1001	0111	Accept permanent handoff
30	1001	1101	Coordination in transition zone message
31	1001	1100	Track alert message
(f) Sensor to Sensor Status Messages			
32	0111	0001	Sensor status message (routine)
33	0111	0010	Sensor status request (about third sensor)
34	0111	0011	Sensor status response (about third sensor)
(g) Sensor to Sensor North-Mark Message			
35	0000	0001	North-mark message
(h) Sensor to Sensor ATCRBS Data Exchange Messages			
36	1101	1000	ATCRBS data request/cancel (from IPC to network management)
37	1101	0001	ATCRBS data start
38	1101	0010	ATCRBS data stop
39	1101	0011	ATCRBS data request
40	1101	0100	ATCRBS track data
41	1101	0101	ATCRBS cancel request
(i) ATC to Message Routing			
42	0000	0010	Data link capability request

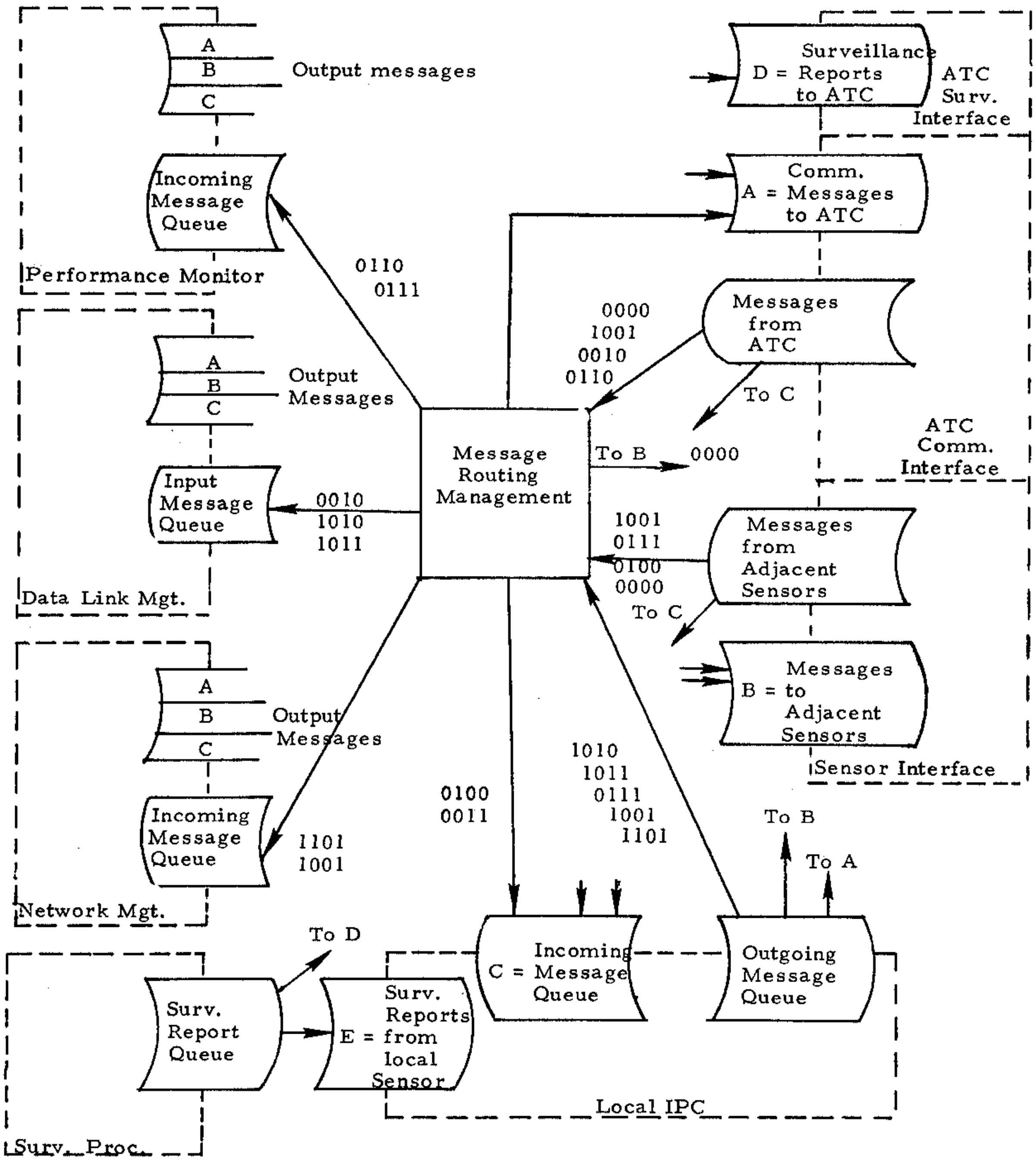


Fig. 17. Context of message routing function

TABLE 6

OUTPUT MESSAGES OF THE SENSOR FUNCTION BYPASSING MESSAGE ROUTING

(a) Output messages from the performance monitoring function
- Status message to adjacent sensor (buffer B)
- Status message request (about third sensor) (buffer B)
- Status message response (about third sensor (buffer B)
- Status message to local IPC (buffer C)
- Status message to ATC (buffer A)

(b) Output messages from data link processing
- ELM downlink (buffer A)
- ATCRBS-ID notice (buffer A)
- Pilot acknowledgment
- Pilot test request (buffer C)
- Tactical downlink
- Uplink message delivery notice
- Duplicate IPC message delivery notice (buffer A)

(c) Output messages from network management
- Track data from remote sensor via local network management to local IPC
- Track alert message (buffer A)
- Network control messages (buffer B)
- Data link capability message (buffer A)

(d) Output messages from surveillance processing
- Surveillance rerorts for DABS, ATCRBS and radar targets (to buffer D)
- Surveillance reports for DABS, ATCRBS (to buffer E, in different format)

Table 7

Messages for Direct Communications With IPC

(a) IPC to IPC
- Conflict table messages

(b) IPC to ATC
- Controller/alert message

function originating the message. This direct link is illustrated in Fig. 17 by using a common letter for two buffers. For example, if the data link processing function wants to transfer a message to the sensor interface, the message is placed in buffer B directly accessible for reading by that interface. Similarly, a message to the local IPC function is placed in Buffer C, and a message to the ATC interface placed in buffer A. The messages handled this way are listed in Table 6. For messages listed under (b) in Table 6 for which no buffer is indicated, the destination depends on the sender of the original message. If a message is to be sent to all ATC facilities, the message is placed in the appropriate buffer (A) with an all-zero address. If all IPCs are to receive the message, the message is placed in buffer C and a copy in buffer B with an all-zero address. A message to all ATCs and IPCs is placed in buffer C and in buffers A and B with an all-zero address. If a unique destination is intended such as is the case for a response message, the appropriate buffer is chosen and the specific address provided.

Besides all flow of messages already discussed, there is a direct flow of messages between IPC function at different sensors and between IPC and the ATC facility. For completeness, the types of messages involved are shown in Table 7.

8.2.2 Tasks of Message Routing

The basic task of message routing is to read the prefix of the type code of the messages coming from the interface or IPC and transfer the message to the appropriate buffer. Additional processing is done for a limited number of message types.

For messages to data link processing (prefixes 0010, 1010, and 1011), message routing management first checks the target track status S of the DABS target in the surveillance file. If no track entry exists, the uplink message (of any kind) is dropped and a message rejection/delay notice issued to the sender (ATC, local IPC, or remote IPC via remote sensor). The content of the message indicates the reason for the rejection. If a track entry does exist, but the track status is not S_4, the same message is issued, with the qualifier indicating the unsatisfactory track status. The uplink message, however, is not dropped but put in the input message queue. If the track status is S_4, the message is put in the input message queue. For all messages put in the input queue, the storage location of the DABS target entry in the surveillance file is appended to the message. In addition, the IPC-ID field is appended to the messages from the local IPC. The message rejection/delay notice from message routing is not indicated on Fig. 17.

When an uplink message cancellation request (number 5, 12, or 17 in Table 5) is received, action differs slightly according to type code. However, in all cases a search is made through the input message queue of data link processing to identify the message to be cancelled (by matching DABS ID and message number). If it is found, it will simply be erased. If it is not found, the uplink message cancellation request is added to the input message queue for further consideration by data link processing.

For multilink type messages (numbers 16, 17, and 18) a copy of the message will be sent to the adjacent assigned sensors in addition to the action taken for the corresponding monolink type message.

Message routing will intercept any uplink message coming from the IPC function (numbers 11, 12, 13, 16, 17, and 18), format a duplicate of the message, and send it to all connected ATC facilities. The purpose of this is to permit recording of all IPC generated command messages. This set of messages is complemented by the duplicate IPC message delivery notice that is sent to ATC by data link processing.

Of all the messages handled by message routing, only two types are addressed to message routing (type code prefix 0000). They are the northmark message, and the data link capability request. The latter allows a user (ATC) to request the 6-bit data link capability on any DABS target in the surveillance file. Message routing will read the data link capability field from the surveillance file and formulate a data link capability message in response to this request.

The northmark message indicates the time that the antenna boresight of the listed sensor passed true north. It is used to update a local table of northmarks for a predetermined set of sensors, which is used by channel management for certain modes of scheduling ATCRBS. Provision is made for a local sensor to receive the northmarks of a nonconnected adjacent sensor. This is accomplished through a relay of these messages through mutually connected sensors.

A group of messages (8, 9, and 10) are addressed to network management, but are not network control messages. The first is the altimeter correction message from ATC which updates the list of altimeter correction values of the coverage map file (see Appendix B). Since more than one ATC may supply data for distinct zones on the same map, the values must be specified together with zone identification or, alternatively, the complete list for which the ATC is responsible is updated with each message, listing the values in a predetermined order.

The ATC failure/recovery and the all radar data request message control the dissemination of surveillance reports to the ATC facilities. In normal circumstances a dissemination lookup table is used for each surveillance report to determine the ATC destinations. In case of an ATC failure, this table is bypassed and all available reports are sent to all operational and connected ATC facilities.

The reports nominally disseminated are beacon reports, uncorrelated radar reports, and radar reports that correlated with coasted beacon tracks. All other search radar reports are normally suppressed except when required by an all radar data request message from a specific ATC facility. Other PCD messages disseminated are the strobe, map, status and real time quality control (RTQC) target reports.

SECTION 9

9.0 DABS/IPC INTERFACE

Although the message flow through this interface has been described as part of message routing in Section 8, it is summarized here separately for clarity and additional detail.

9.1 Functional Interaction

The IPC function supported by DABS uses surveillance data to detect conflict situations and exploits the data link capability to resolve these conflicts. Since the DABS sensor functions of surveillance and data link have been kept separate from the IPC function in the equipment design requirement, a DABS/IPC interface exists.

Information flows across this interface in both directions. The interface itself may consist simply of common buffers, with an arrangement for accessing these buffers (both for reading and writing), in a way that will minimize delays and interference.

Besides the DABS/IPC interface considered here, the IPC function interfaces with ATC and IPC facilities located at remote sensors. Controller communications, consisting of controller alert notices, flow across the IPC/ATC interface. The IPC/IPC communications consist of messages containing conflict tables information.

The specific nature and method of the information exchange through the DABS/IPC interface are described below.

9.2 Data Flow From DABS to IPC

Messages to IPC may be separated into two classes: surveillance reports, and data link messages. Surveillance reports usually originate at the local sensor but, in exceptional circumstances, are provided by a remote sensor. In any case, surveillance reports will be forwarded to the IPC target report buffer with a maximum delay of 1/8th of the scan period after acquisition by the local sensor.

This buffer consists of two segments in order that one segment may be filled by DABS while the other is being read out by IPC. Each segment is protected by a lock flag, set by IPC when reading in order to prevent DABS from overwriting the segment. When DABS completes the writing of the reports for one sector, in addition to all reports received from remote sensors since the last buffer segment was written, it generates an interrupt to IPC. IPC then commences to process that segment by coordinate conversion to its x-y system, and by updating its track. IPC conflict calculations are done independently of azimuth sector and are performed nominally at a rate of once every two seconds.

The formats of the surveillance reports are shown in Table 8. Reports from remote sensors are in $\rho\,\theta$ coordinates. The sensor to sensor interface routinely attaches the ID of the sender to all incoming messages. This ID is forwarded to IPC to allow for proper coordinate conversion.

Data link messages to IPC consist of status messages, pilot acknowledgments, and response messages such as notices of delivery or rejection of IPC uplink messages. Figures 18 and 19 illustrate the message flow toward IPC.

9.3 Data Flow From IPC Toward DABS

IPC issues messages to the sensor functions via message routing which forwards them (based on the type code) to the proper local destination. Figure 20 shows the message flow to local sensor functions. When IPC decides to attempt uplinking messages via several sensors at the same time (always including the local sensor), the type code will reflect this "multilink" character. Message routing will then forward the message to the local data link management and at the same time to all other sensors which are "assigned" to cover the given target. Message routing will perform an acceptance test on IPC

TABLE 8

DABS SURVEILLANCE DATA SENT TO IPC	
Fields	Length (bits)
Test	1
Format type	2
Radar substitution	1
Mode C present	1
Sensor priority status	4
Permanent handoff in progress	1
Radar reinforced (*)	1
Code 7700	1
Code 7600	1
Alert	1
IFR/VFR	1
Reply type	3
Null report (*)	1
Track start (*)	1
Track drop (*)	1
Range, LSB = 1/16 μsec	16
Azimuth, LSB = 0.002°	14
Mode C altitude, LSB = 100 feet	12
DABS identification	24
Sensor identification	4
Measurement time	8

ATCRBS SURVEILLANCE DATA SENT TO IPC	
Fields	Length (bits)
Test	1
Format type	2
Radar substitution (*)	1
Mode 3/A present	1
Mode C present	1
Mode C not decoded	1
SPI (IDENT)	1
Radar reinforced (*)	1
Code 7700	1
Code 7600	1
False target flag (*)	1
Null report (*)	1
Track start (*)	1
Track drop (*)	1
Range, LSB = 1/16 μsec	16
Azimuth, LSB = 0.022°	14
Mode C altitude, LSB = 100 feet	12
Mode 3/A	12
ATCRBS surveillance file no. (*)	12
ATCRBS code in transition (*)	1
Sensor ID	4
Measurement time	8

*Results of correlation decisions.

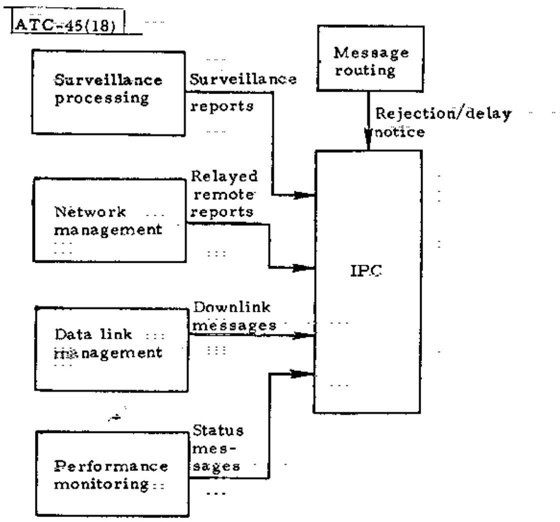


Fig. 18. Message flow - local sensor functions to IPC.

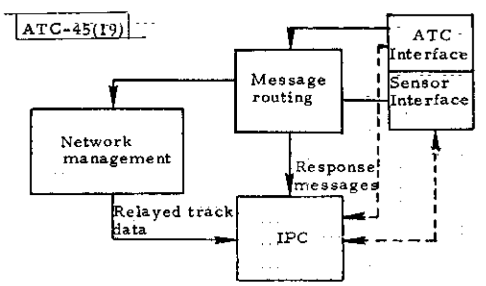


Fig. 19. Message flow-ATC facility or remote sensor to IPC.

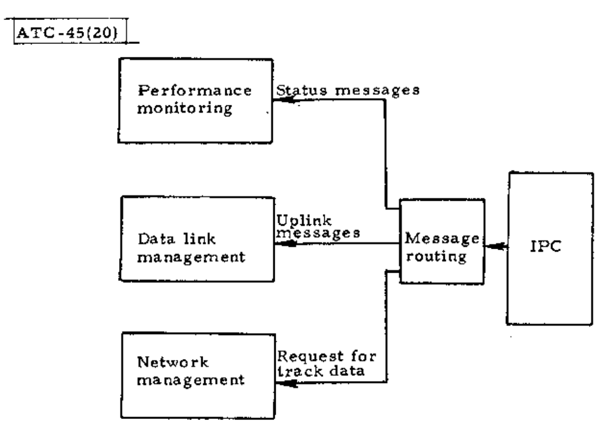


Fig. 20. Message flow - IPC to local sensor functions.

uplink messages, and issue a rejection or a delay notice to IPC as applicable. It will also format a duplicate of all accepted IPC uplink messages and forward these to designated ATC facilities for recording purposes.

SECTION 10

10.0 ILLUSTRATION OF TYPICAL NETWORK MANAGEMENT ACTIVITY

In this section, network activity is illustrated for a single thread flight. The network in this example has triple coverage capability, but only two sensors are assigned (MNAS = 2) for a target at sufficient altitude. Figure 21a presents the flight on the coverage map of sensor A. Figure 21b shows the same flight on the map of sensor B. Cell number 1 is the zenith cone. The shaded area is the transition zone.

Assume the flight example starts at the point labeled 1, and at high enough altitude to be visible to both sensors A and B.

At point 1, sensor A is assigned primary.

At point 2, sensor A finds from the map that now sensor B is also assigned. Sensor A sends a data start message to sensor B which starts up a track in status S_3. Sensor A sends track data messages to sensor B scan after scan.

At point 3, sensor B has successfully acquired the target. Its track status is now S_4, and sensor B asks sensor A to cancel the track data flow to which sensor A replies with a data stop.

At point 4 the coverage map lists a new sensor, C. However, MNAS being restricted to 2, there is no activity.

At point 5 assume that the target fades for sensor A. Sensor A sends a data request to sensor B and at the same time hands off its priority status. Sensor A temporarily adopts secondary status ($PS_A = S_T$ and $PS_B = P_T$).

At point 6, sensor A reacquires and sends a cancel request to sensor B requesting cancellation of track data and of the priority hand off. Sensor A adopts $PS_A = P$, and B resumes $PS_B = S$.

At point 7, sensor A hands off priority to sensor B($PS_A = S$, and $PS_B = P$).

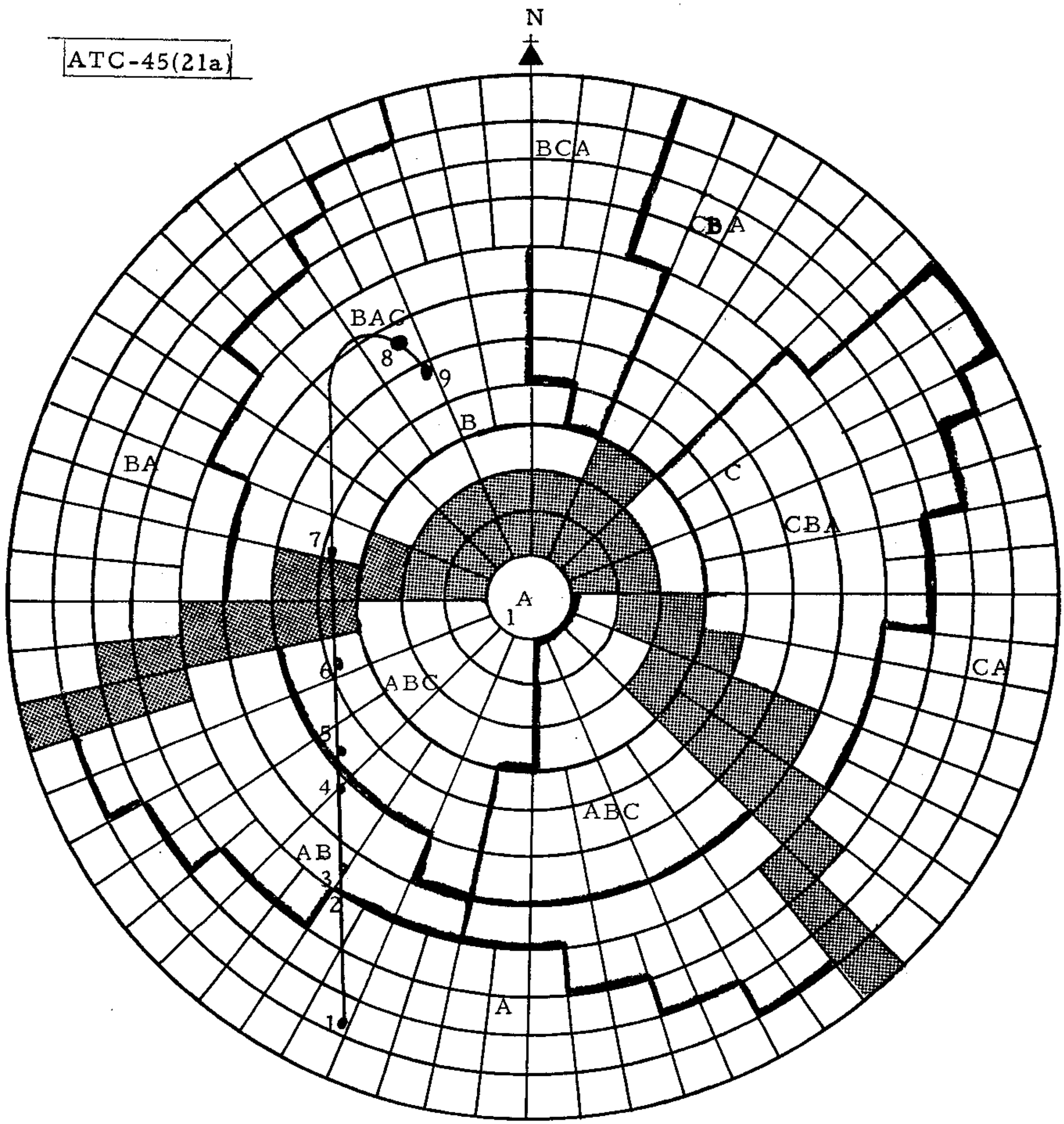


Fig. 21a. Typical flight illustrating NM activity- Map of Sensor A.

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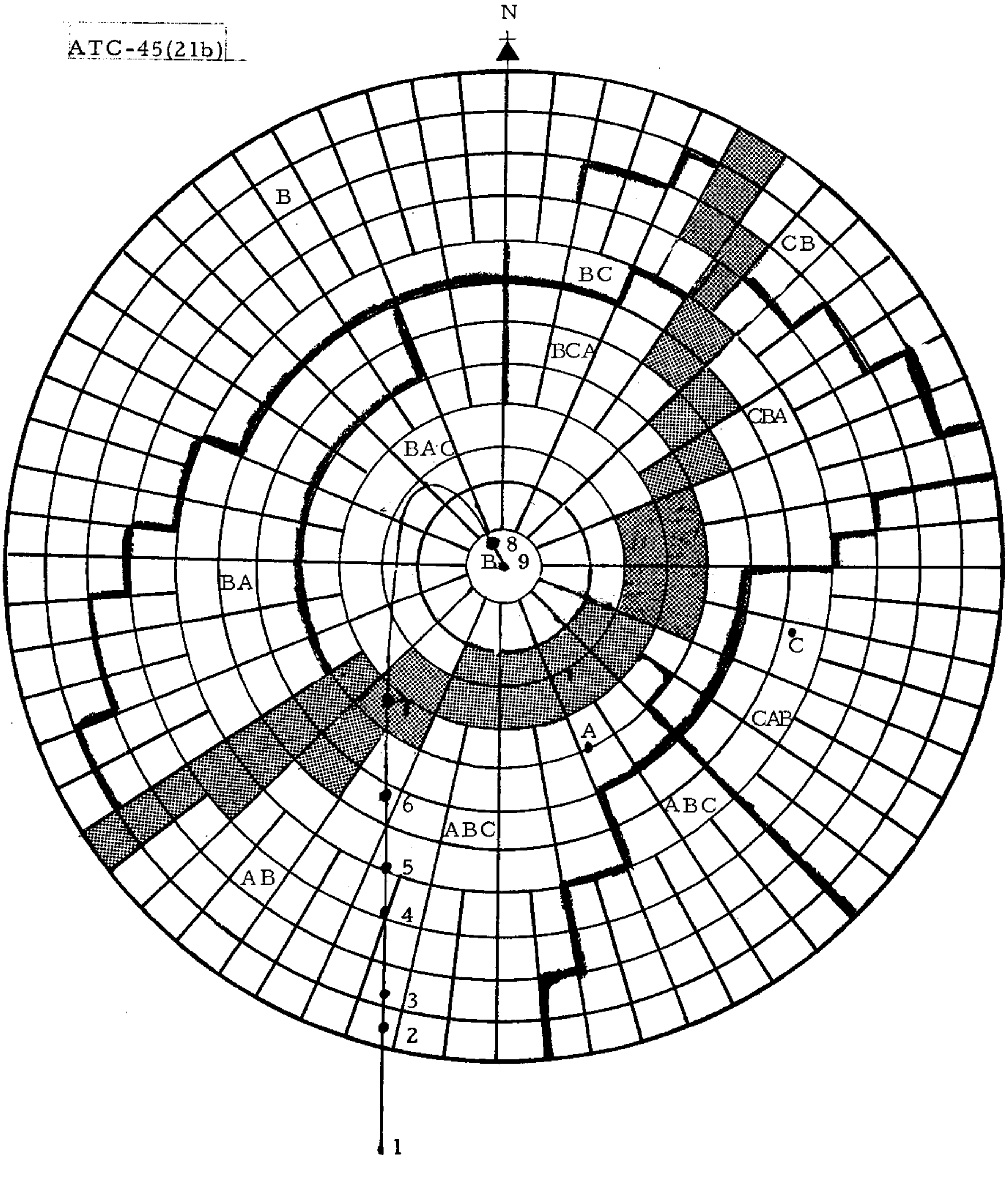

Fig. 21b. Typical flight illustrating NM activity- Map of Sensor B.

At point 8, the target enters the zenith cone of B which issues a data request to A. Sensor A issues a data start followed by track data.

At point 9, the target is so low that sensor A can no longer interrogate, and it issues a data stop to sensor B. After that the aircraft touches down at airport B.

REFERENCES

[1] Drouilhet, P.R., "The Discrete Address Beacon System (DABS): A System Description," Project Report ATC-42, M.I.T. Lincoln Laboratory, FAA-RD-74-189 (18 November 1974).

[2] Reiner, D., and Vandevenne, H., "Provisional Message Formats for the DABS/NAS Interface, "Project Report ATC-33, M.I.T. Lincoln Laboratory, FAA-RD-74-63 (25 April 1974).

[3] Report of "Automated Data Interchange System Panel - Fourth Meeting," ICAO, ADISP-WP-84, November 1972. Updated with ICAO Memorandum SP 24/1-64 (1 March 1974).

[4] Drouilhet, P. R., "Provisional Signal Formats for the Discrete Address Beacon System" (Revision 1), Project Report ATC-30, Rev. 1, M.I.T. Lincoln Laboratory, FAA-RD-74-62 (25 April 1975).

APPENDIX A

COVERAGE MAP EXAMPLE

A. 1 Introduction

The purpose of this appendix is to present an example of a network implementation in order to help clarify various concepts related to the coverage map such as sensor assignment over an area and for a particular DABS target, sensor priority, transition zones, subareas, altitude break points, and many others.

The coverage map that will be illustrated in this appendix applies to the three sensor DABS network shown in Fig. A-1. In order to simplify the presentation, certain assumptions have been made. They are:

1. The three sites have a maximum range of approximately 60 nmi.
2. The altitude of the three sites is at sea level.
3. There are no natural or man made obstacles to interfere with the line of horizon.
4. The cone of coverage for each site has a horizontal cutoff angle of 0. 5 degree.

The change to be made to the map, if any of these assumptions were to be omitted, would follow in a very straightforward way once the basic map construction concept has been understood. It is just such changes that make coverage maps very site specific.

The approach followed in this example is to start with the general allocation of coverage areas as shown in Fig. A-1 and proceed gradually to the construction of the coverage map for one individual site.

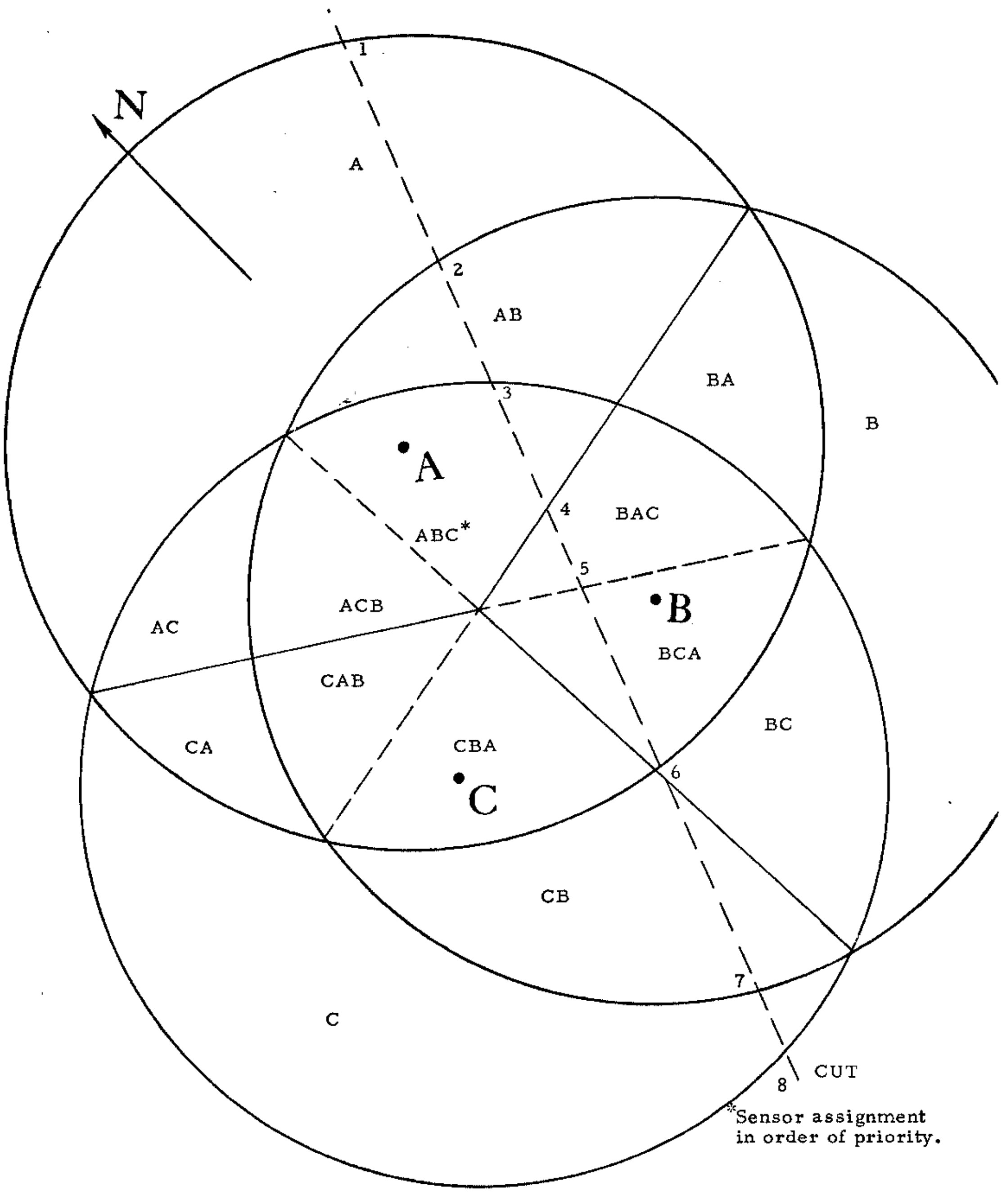

Fig. A. 1. Theoretical sensor assignment in the horizontal plane.

A. 2 General Description of Coverage Assignments

The data required for map construction include the relative site locations, characteristics of each site such as site altitude, radar range, local horizon and topographical features around the site. Other information includes the description of special areas such as zones where ATCRBS lockout of DABS targets is prohibited, the outline of the IPC zone of responsibility for each sensor, the outline of zones where a different altitude adjustment value must be provided to aircraft, and other information. From this a picture of general coverage assignments will emerge as in Fig. A-1 (in the horizontal plane at high altitude) and in Fig. A-2 (in the vertical plane). Figure A-2 illustrates coverage in a vertical plane erected on the line indicated on Fig. A-1 as "cut." The numberings indicate boundary intersections and are common to both figures.

The cone of coverage, as illustrated in our idealized case, intersects with the vertical plane as a hyperbola, below which the sensor cannot provide coverage. As illustrated in Fig. A-2, the general sensor assignments change with altitude. The sensors are listed in Figs. A-1 and A-2 in order of priority, the highest priority being assigned to the sensor able to cover at lowest altitude. The sensor with highest priority is called the primary sensor for a given area, and the area is the primary area for that sensor. In the primary area the sensor is assigned for coverage to the ground level. This means that the primary sensor will not abandon interrogating a target at very low altitude simply because the coverage map indicates it cannot see it. The cutoff angle is a rather artificial concept to reflect lower radar power levels for radiating energy at small elevation angles.

In the total area of possible coverage, determined by the maximum range of the sensor, the sensor can then be ranked as primary or nonprimary (i. e., secondary, tertiary, etc...). As a rule the area where the sensor is ranked less than tertiary or third best, is not included in the coverage map. In the area where the sensor is primary, the sensor will be asked to perform a set of additional tasks besides providing coverage as was explained in the main body of this report. Figure A-3 illustrates where sensor A is primary, secondary or tertiary.

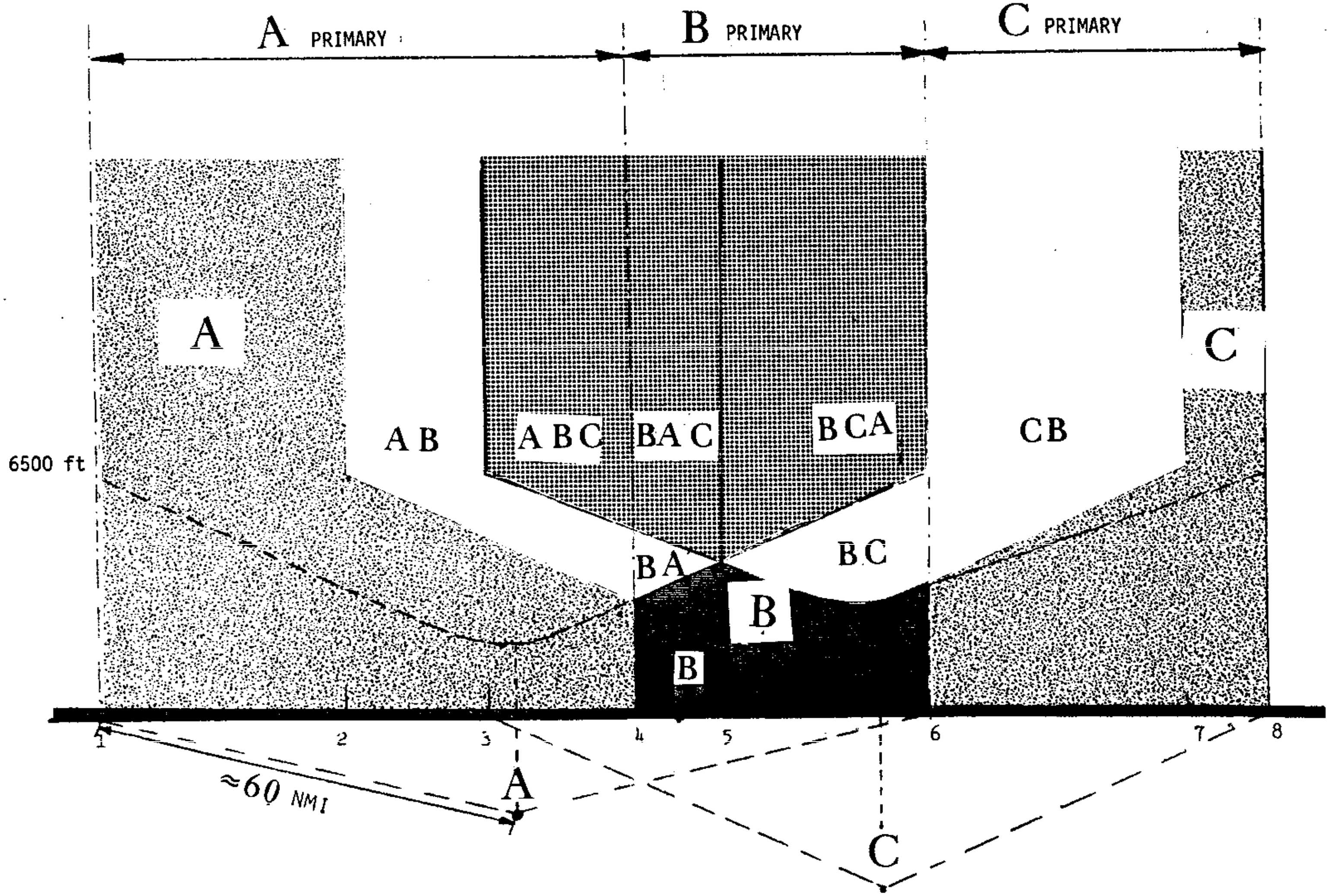

Fig. A.2. Theoretical sensor assignment in the vertical plane of the cut.

A.4

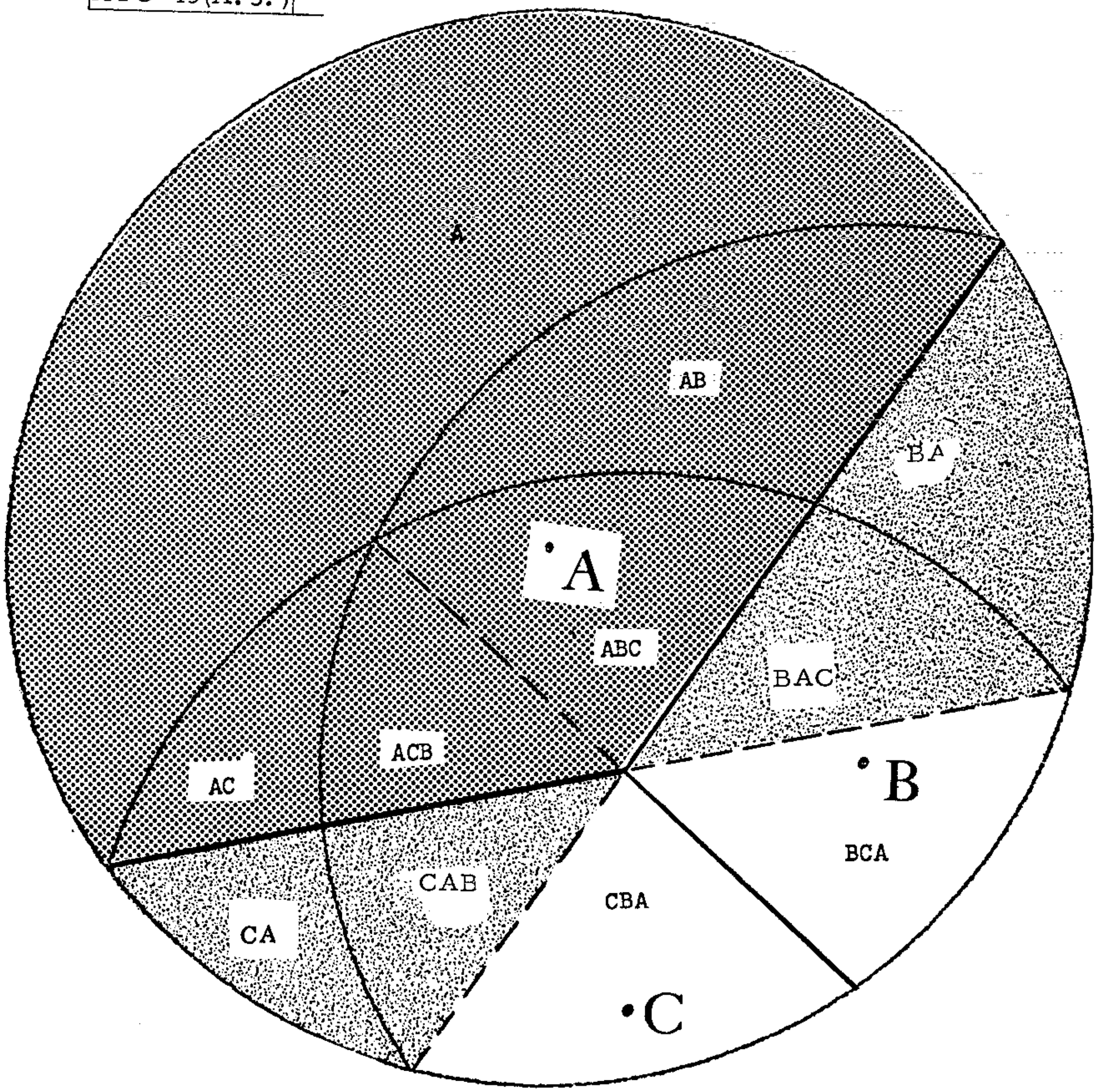

Fig. A3. Primary and secondary areas for sensor A.

= primary

= secondary and tertiary

A. 3 Extent of Area Considered for the Coverage Map

The area considered for the coverage map never extends beyond the maximum range of the sensor. The sensor is never assigned in an area together with another DABS sensor with which it has no direct ground communications. The reason for this is that direct communications between assigned sensors is needed for surveillance or control (IPC) handoffs and is a basic condition for successful network management. As stated before, the area where the sensor is ranked among adjacent sensors as lower than tertiary is not considered part of the map.

The areas in the coverage map thus excluded are called the "forbidden zone." The area included in the map is divided into an inner zone (closest to the site) where the sensor is "required" to provide coverage. The remaining zone is the "permitted" zone, to which the sensor extends coverage in exceptional circumstances such as during adjacent sensor failure and for a target leaving the required zone.

The extent of the "required" zone depends on the specific site configuration and a system parameter MNAS defined in the adaptation data for the sensor. The maximum number of assigned sensors (MNAS) determines the maximum multiplicity of coverage to be exploited (where available). Nominally MNAS will equal two, in which case the "required" zone includes the primary and secondary area of coverage of the sensor. In the "required" zone the sensor will be "assigned" for a specific DABS target if the target altitude exceeds the altitude breakpoint of the sensor (to be defined).

The definition of the "required" and "permitted" zones depends not only on the value of MNAS, but also on the "reading mode" adopted to read the coverage map. When a failure of an adjacent sensor is declared, the "special reading mode" is adopted; the net result of which is that part of the permitted zone of the local sensor that was required for the failed sensor will now be redefined as required for the local sensor. The precise way in which the mode change effects this re-assignment of sensors was explained in the main body of this report.

In our ongoing example, we chose MNAS = 2, so that the primary and secondary in Fig. A-3 also determine the "required zone" for A.

A. 4 The Grid Structure

A grid is used to quantize the total area of the map. The part of the grid relevant to our example is shown in Fig. A-4, to cover a maximum range of about 60 mni. The incremental area created by the grid is called a cell. The coverage map in the computer consists of a file in which a set of parameter values will be listed for each cell.

All areas outlined in the general map description must now be approximated in terms of a number of whole cells. Some general rules can be followed when approximation is required. For example, the local sensor approximates its own area of coverage by the minimum number of cells needed to completely include the boundary. This extends the approximated area slightly beyond the theoretical area. Conversely the local sensor approximates the coverage area of an adjacent sensor generally by the maximum number of cells that can be fit inside the given area boundaries. The approximation is then smaller than the theoretical area.

The simple rule expressed above creates small areas of overlap. This is of no great importance for boundaries involving secondary assignment, but is important for primary assignment. Figure A-5 shows the overlap created when primary boundaries are implemented by the three different maps. In subsection 6. 4 another reason (no gaps in primary assignment in the vertical dimension) was cited as to why it may be necessary to widen the overlap already existing. Due to the use of slant range, the width of the overlap should be at least as large as the bias in position of the target as seen by the two sensors involved in a primary boundary. Figure A-6 illustrates the bias for a maximum altitude of the target equal to 10 nmi. It is seen that the overlap in Fig. A-5 is sufficient.

The overlap area is approximated in the map by a number of whole primary cells. The zone thus created by imbedding the overlap area is called the transition zone shown in Fig. A-7 for sensor A. The coverage

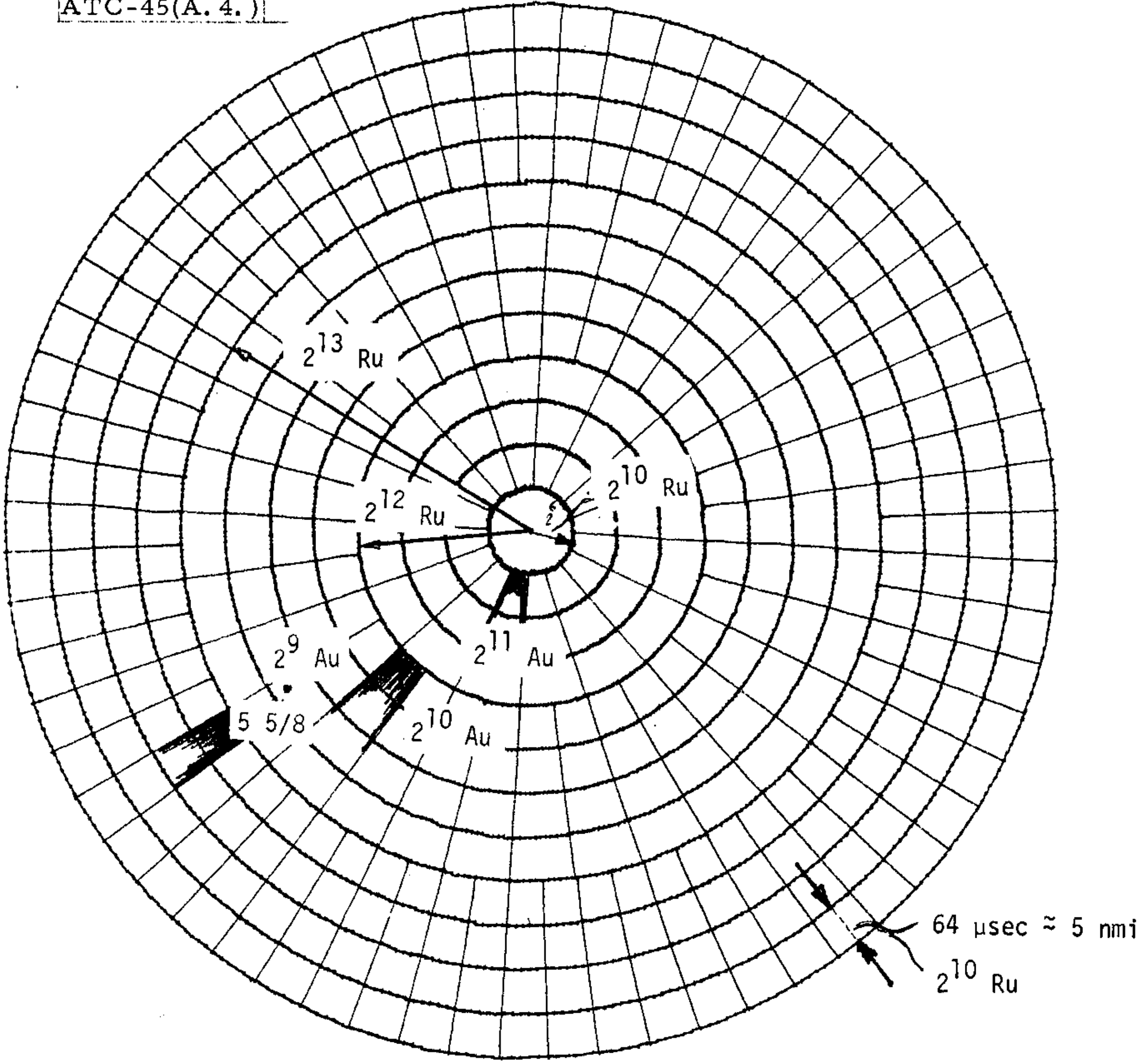

Fig. A.4. The grid structure used to quantize the coverage map.

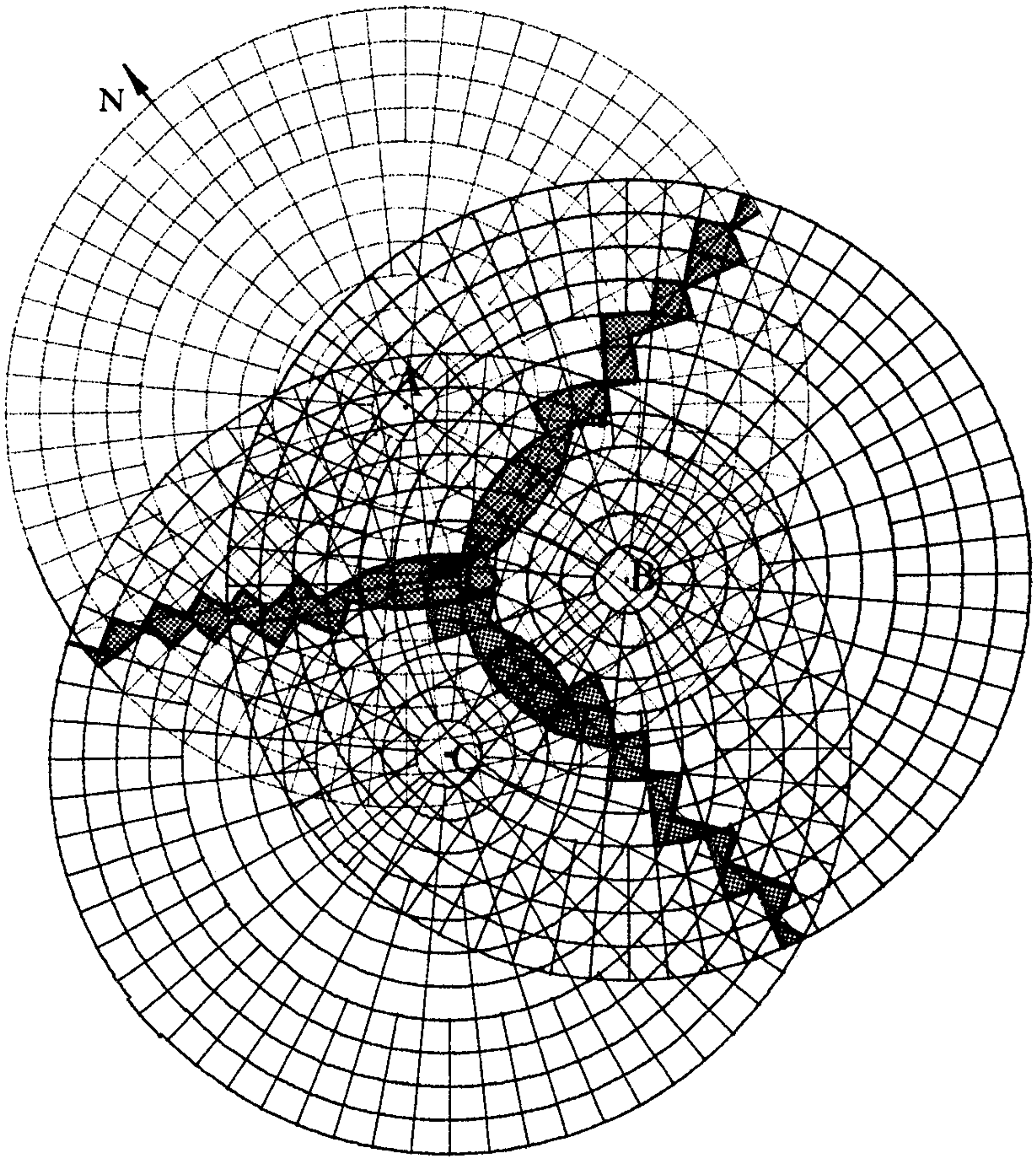

Fig. A.5. Ambiguity areas in primary assignment.

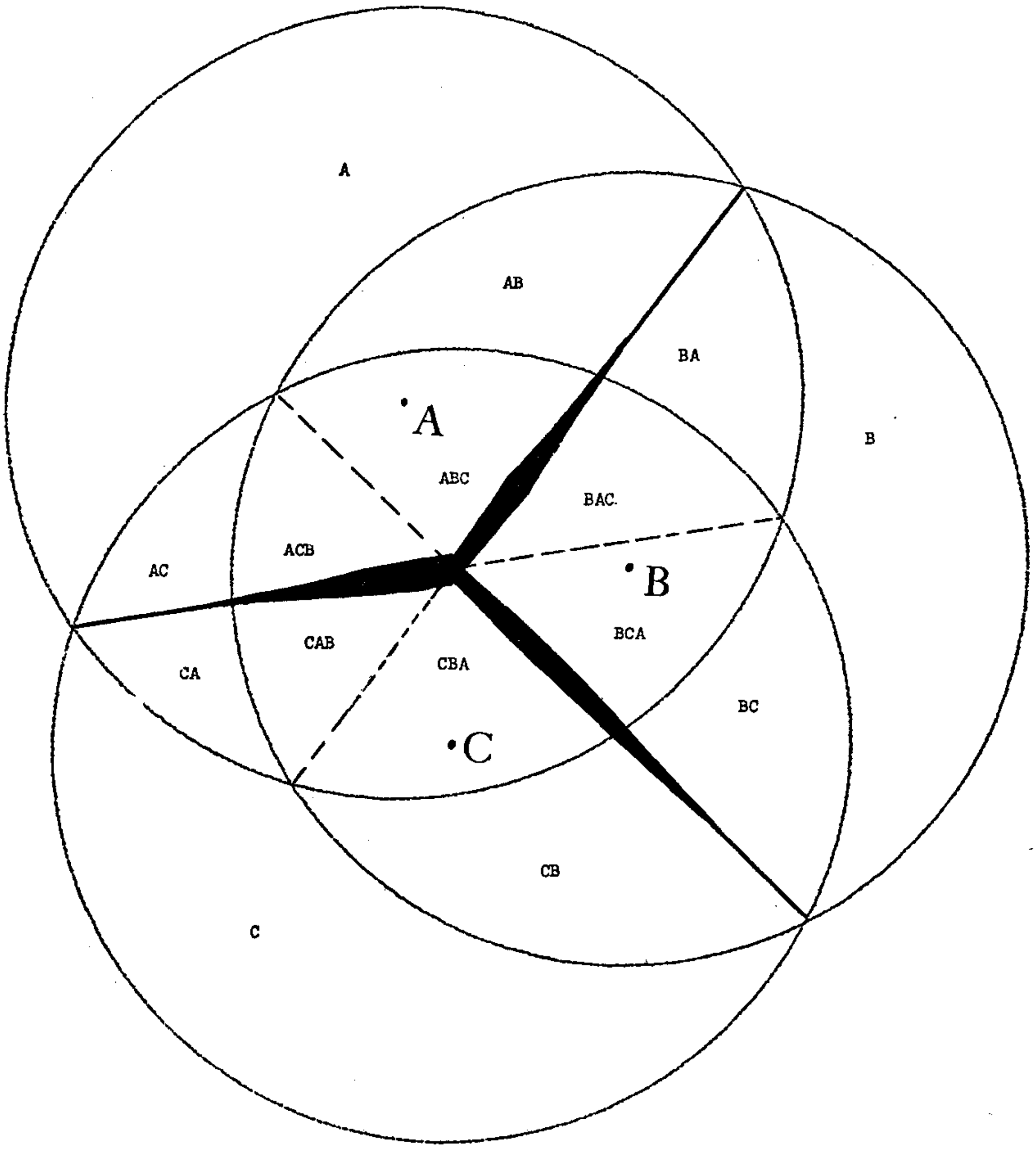

Fig. A.6. Altitude induced position bias at the primary area boundary.

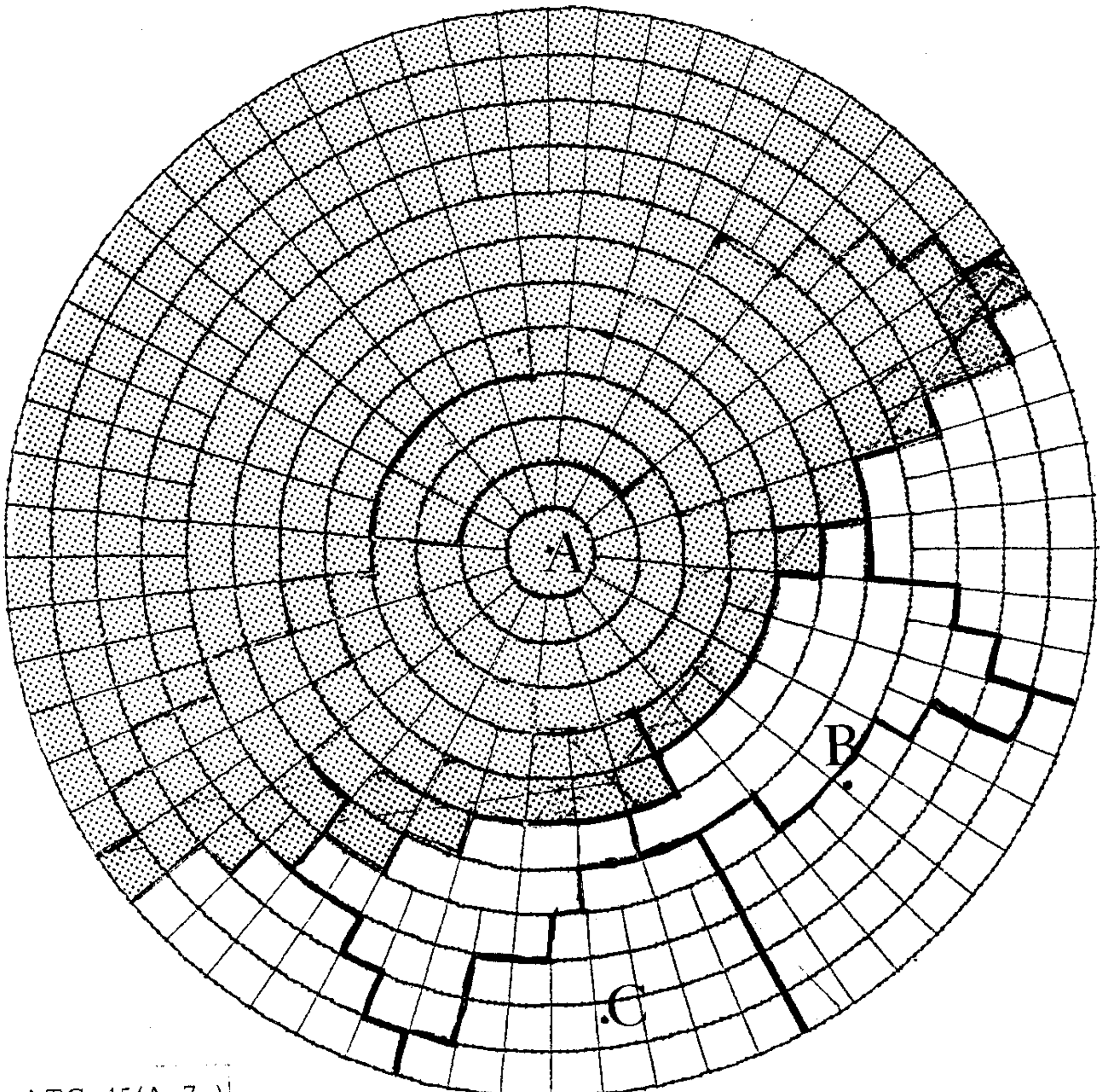

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Fig. A.7. Primary, transition and secondary zones for sensor A.

map for sensor A is now complete (for the features considered in the example) and shows the primary, secondary, and transition areas.

A. 5 Cell Content

The key to the retrieval of information from the map is the cell index. If one adheres to the numbering scheme shown in Fig. A-8, the cell index may be calculated from a given set of coordinates (ρ, θ) using the algorithm given in Table A-1. The several subareas relevant to the coverage map of sensor A are shown in Fig. A-8. The content of the map is illustrated in Fig. A-9 for two arbitrarily chosen cells (numbers 89 and 206). The altitude breakpoints indicated are multiples of 500 ft; for example $h_2 = 8$ means that the altitude breakpoint for the second highest priority sensor (sensor C) is 8 x 500 = 4000 ft. It is possible that over the total area covered by the three sensors, different altimeter adjustments for barometric pressure must be applied. The example illustrates the case that a different value is applied over the primary area of each sensor.

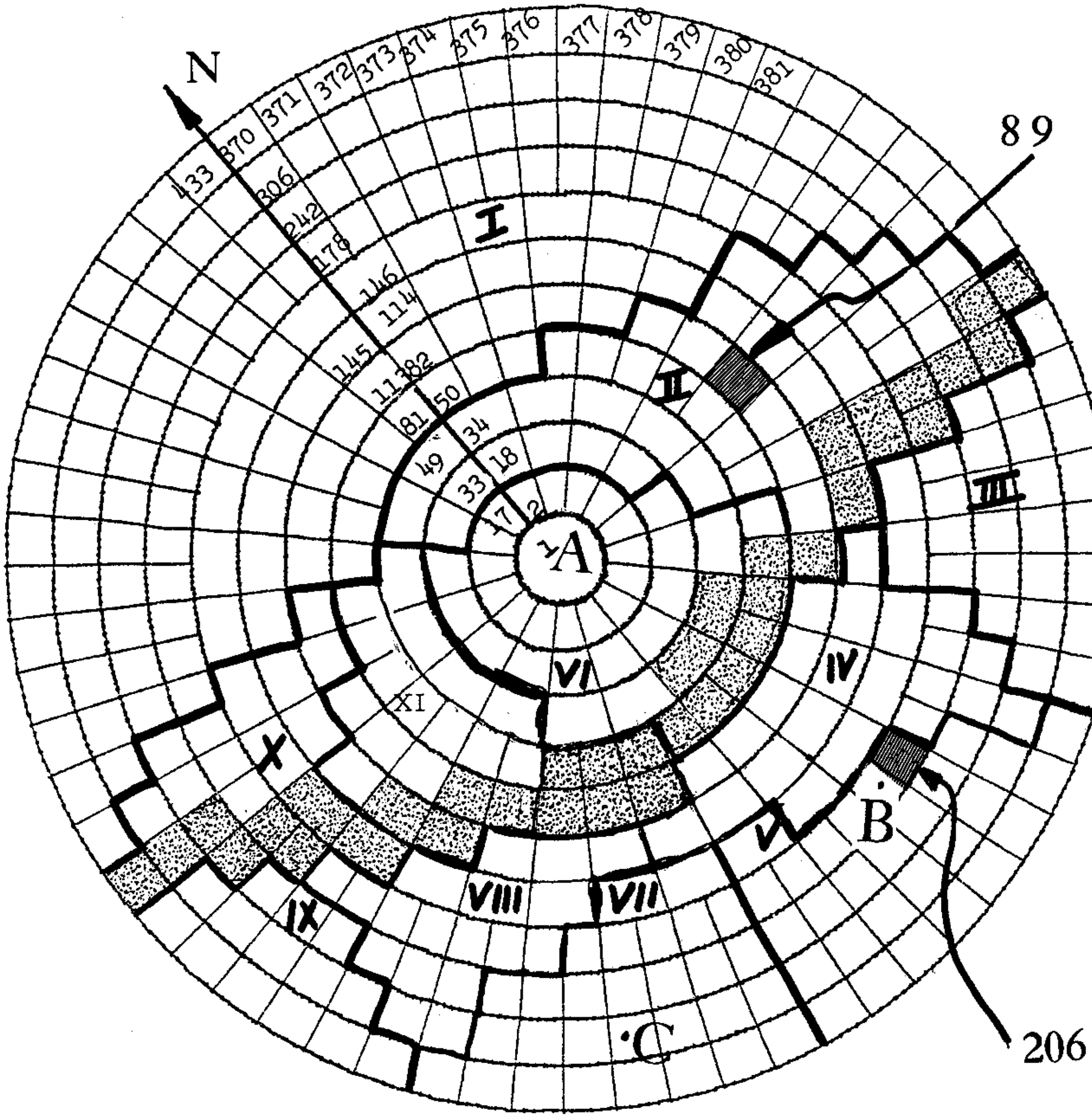

Fig. A.8. Cell index numbering; sub-area numbering.

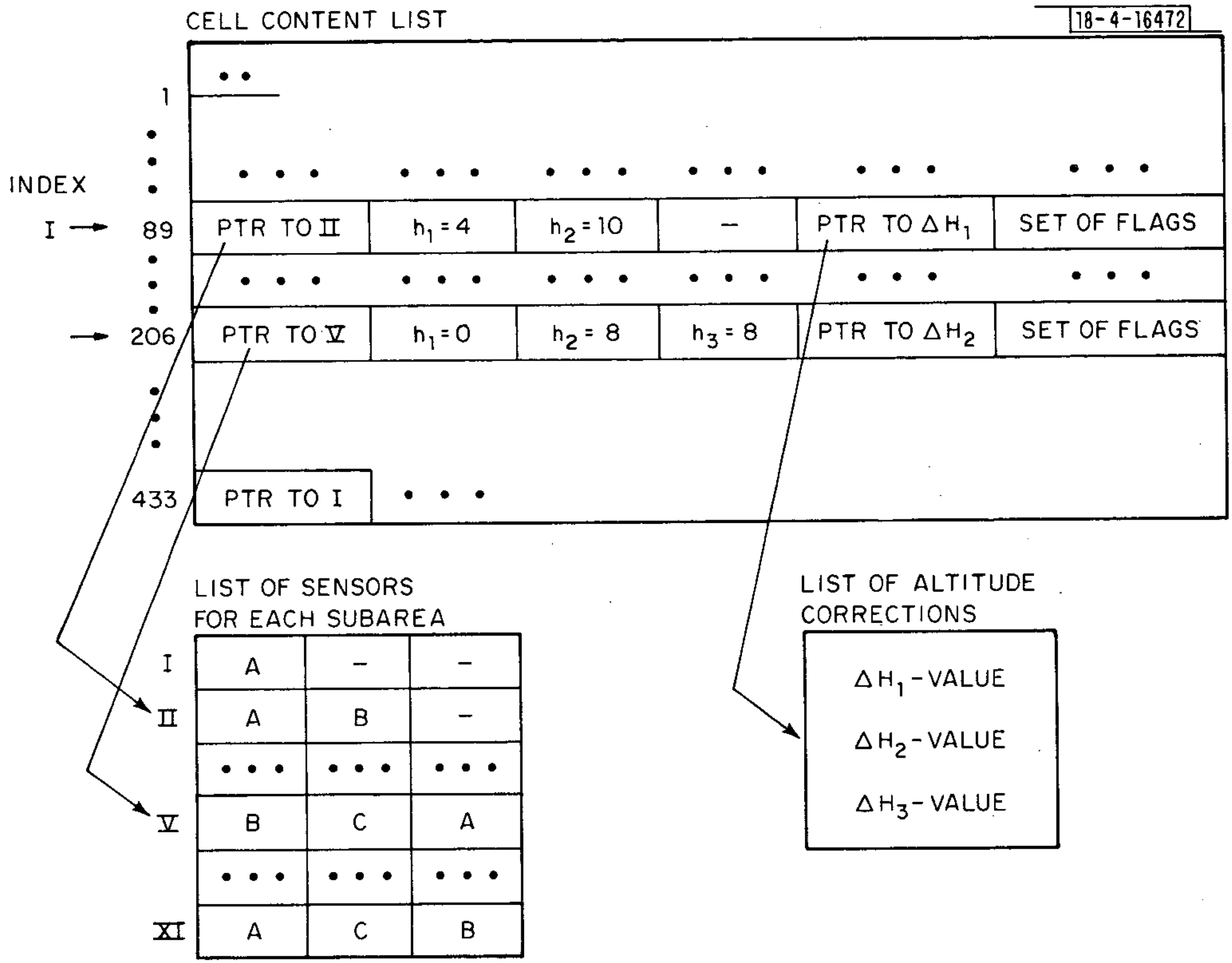

Fig. A.9 File structure for coverage map.

TABLE A-1

CALCULATION OF CELL INDEX I

Let ρ and θ represent the measured target position (16 bits for range in range units, 14 bits for azimuth in azimuth units).*

Let θ_1, θ_2 and θ_3 represent the quantized azimuth fields made up of the 6, 5, and 4 most significant bits of θ.

Let X_1 and X_2 represent the quantized range fields made up of the 5 and 6 most significant bits of ρ.

The Cell Index I can then be obtained via the algorithm:

If $(X_1 - 8 = Y) \geq 0$, $I = 64\,Y + 690 + \theta_1$.

Otherwise,

if $(X_2 - 8 = Z) \geq 0$, $I = 64\,Z + 178 + \theta_1$.

Otherwise,

if $(X_2 - 4 = R) \geq 0$, $I = 32\,R + 50\,\theta_2$.

Otherwise,

if $(X_2 - 1 = Q) \geq 0$, $I = 16\,Q + 2 + \theta_3$.

Otherwise,

$I = 1$.

* One range unit equals approximately 30 ft.
One azimuth unit equals $\pi\ 2^{-13}$ radian.

APPENDIX B

REPERTOIRE AND FORMATS OF NETWORK CONTROL MESSAGES

Messages exchanged between sensors for the purpose of network management are defined as network control messages. In this appendix the list and the specific data fields in each message are presented. Transmission of these messages between sensors over the ground data link must conform to the protocols and formats of the common ICAO Data Interchange Network (CIDIN) for a balanced point to point configuration. The message formats presented here relate only to the link "data field" of the message in CIDIN terminology. The messages are:

<u>Data Start Message</u>

Type code	DABS ID	Meas. range	Meas. azimuth	Range rate
1 - 8	9 - 32	33 - 48	49 - 62	63 - 70

Azimuth Rate	Altitude	Time-reference	Trans. capability
71 - 78	79 - 90	91 - 98	99 - 104

Roll call inhibit	Sender ID
105	106 - 109

Track Data Message

Type code	DABS ID	Meas. range	Meas. azimuth	Range rate
1 8	9 32	33 48	49 62	63 70

Azimuth rate	Altitude	Time reference	Sender ID
71 78	79 90	91 98	99 102

Data Stop Message

Type code	DABS ID	Sender ID	Temporary primary handoff indicator
1 8	9 32	33 36	34

Sender ID
35 38

Data Request Message

Type code	DABS ID	Temporary primary handoff indicator: Start	Sender ID
1 8	9 32	33 34	35 38

Cancel Request Message

Type code	DABS ID	M	Temporary primary handoff indicator: Cancel	Sender ID
1 8	9 32	33	34 34	35 38

M = 1 to signal cancellation of temporary handoff only, M = 0 to signal cancellation of data request and of handoff if that indicator is set.

Permanent Handoff Message

Type code	DABS ID	Value	RCI boundary indicator	Sender ID
1 8	9 32	33 33	34 34	35 38

Value = Forced primary handoff to receiving sensor
or forced secondary handoff to receiving sensor

Accept Permanent Handoff Message

Type code	DABS ID	Value	Sender ID
1 8	9 32	33 34	35 38

Value = 1 0 if acknowledging primary handoff
0 1 if acknowledging secondary handoff

Coordination in Transition Zone Message

Type code	DABS ID	Value	Sender ID
1 8	9 32	33 34	35 38

Value = Request for primary or
Primary assignment approved or
Primary assignment disapproved

Track Alert Message

Type code	DABS ID
1 8	9 32

ATCRBS Data Request Message

Type code	ATCRBS code + track nbr of requesting sensor	Range	Az.	Altitude	Sender ID
1 8	9 32	33 48	49 62	63 72	73 76

ATCRBS Track Data Message

Type code	ATCRBS code + track nbr of requesting sensor	Measured range	Measured azimuth
1 8	9 32	33 48	49 62

Range rate	Azimuth rate	Altitude	Time reference	Sender ID
63 70	71 78	79 90	91 98	99 102

ATCRBS Data Start Message

The format is identical to the ATCRBS track data message, but the type code is different.

ATCRBS Data Stop Message

Type code	ATCRBS code + track nbr of requesting sensor	Sender ID
1 8	9 32	33 36

ATCRBS Cancel Request Message

The format is identical to the ATCRBS data stop message, but the type code is different.