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Suitability Analysis of Free Space Optical in Military Communication Technology

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Abstract

ThispaperreviewstheFSOCtechnologyandpresentsfeaturesbasedmeritsaswellasunmatchedadvantages&associatedmajorapplication sinvarious fieldscollatingthemintoasinglereferencepointforfutureresearch.EffortshavealsobeeninvestedtopresentareviewofFSOC'slimitations &innovativeemergingmitigation techniqueswhichcanprovetobeaonestopfeeder&alaunchpadforfutureresearchin FSOCdomain.AliteraturesurveyhasbeenundertakenofavailableFSOCrelatedmilitaryapplicationstoreview&gatherrelevantinputstot hrowlightonemergingtrendsin militaryapplicationsincludingrecentexperiments&researchedareaspertainingtolasersystems&weapons,UnmannedAerialVehicles(UAVs),underseausages,terrestrial applications,aerial,navalships/shorebasedapplications&RF/hybridsystems.Ithasbeenendeavoredtoshedlightonfindings&developmen tsintheseclassifiedmilitarydomainstogenerateinputsforfutureworkinthisdomain.Finally,afuturetechnical roadmapandawayahead&suggestionshavebeencoined

Keywords:FSOC,LineofSight,RF,UAVs,On-offKeying,SubcarrierIntensityModulation,

Bandwidth

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1.Introduction

InFSOC,focusedlightistransmittedthroughfreespacemediumforsendinginformationforcommunicationsinaremotemannerforspace ,terrestrial,aerial,marine,military&civilapplicationsbetweenvarioussourcepoints,receivers(Rx),transmitters(Tx),handsets,machine s,equipmentincludingnetworkswhicharerequiredtobeinLineofSight(LOS).Itboastsofmuchlowercosts&setuptime,protectionfrom ElectromagneticInterference/ElectromagneticCompatibility(EMI/EMC)issues&hasmuchsimplerequipment&infrastructuretha nRadioFrequency(RF)networks.TherearenumerousfeaturebasedmeritsofFSOCincludinghigherBandwidth(BW),betterBitErro rRates(BER)anddatarates.Suchadvantages&featuresorientedmeritshavebeenstudied&collatedherepointwisesoastomakeitasingle pointbaselineforfuturesurveysinFSOCdomain.TheFSOCtransmissionsdegradeduetoenvironmentalfactors&atmosphericturbule nce(AT)likerain,mist,fog,heat,physicalobstructions,scatteringimpediments&dispersingetc.However,numerous

mitigatingtechniqueslikecoding,modulation,channelmodeling,RF/HybridFSOCsolutionsarebeingresearched&developedacrossth eglobe.Apreviewoftheselimitations&emergingmitigationtechniqueshasbeendrawnoutfromvarioussources&preparedasaneasysou rcepointforresearchers.LiteratureonFSOCMilitaryapplications,beingcustomized,sensitive&classifiedinnatureisnotreadilyavailab le.Ithasbeenendeavoredtogathersuchinformationandprovidealogical&practicalfuturisticwayahead.Collationofmitigationtechniqu esalongwithdetailsofemergingtrendsinmilitaryapplicationsisnotacommonplaceandhaverarelybeensurveyed&arrangedtogetherasa nodalreferencewhichhasbeenamotiveinthispaper.

Modulated&collimatedlightasinfrared(IR)lasers,areutilizedinFSOCtotransmitdatabetweenTx&Rxpoints.Itbringsinimport antusefulfeatureslikeenhancedsecuritythroughmuchLowerProbabilityofDetection(LPD)&ProbabilityofIntercept(LPI)wit houtanyinterference&regulationsunlikeRF[1].FSOCisfastshapingupasatechnologyoptionformitigatingbottlenecksofconn ectivityinasupplementaryroletoexistingRFlinks.OpticalWirelessCommunication(OWC)caneaseoutenormousdatatrafficface dinnetworksofmicrowave&RF.Therefore,combinationofRadiooverFSO(RoFSO)&FSO/RFsystemscanbeasuitablesolutionto bear5G&relatedtechnologies.Inthiscontext,paper[2]haspresentedseveralkeytechnologies&applicationsofRoFSOunderliningitssu periority.FSOCisbeinginvestigatedextensivelybecauseitcanimprovethereach&lastmileconnectivityofOFCnetworks,hasrapidre-deployability&higherflexibilityinoperationsrelatedtodisasterrecovery&militaryprojects.Presently,OWChasalreadybeenusedtode

monstrate100Gb/sdatarateapplicationsforbothindoor&outdoorusageinvariedrangesupto10000km.TechnologyoverviewofOWCincludingopticalcamera&visiblelightcommunication,FSOC,Lasersandlightdetectionandrangingarebeingconductedbycontemporaryresearchersworldwide[3].Latestapplications/trendsofFSOCincludesubcarriermultiplexing(SCM),OWCwavelengthdivisionmultiplexing(WDM),visiblelightcommunications(VLC),worldwideinteroperabilityformicrowaveaccess(WiMAX),vehicularvisiblelightcommunications(VVLC),nextgenerationFSOwirelessterrestrial/globalnetworkarchitecture&Deepspaceopticalcommunicationsystems.ResearchersarefacingdifficultiesinevolvingFSOCapplicationsrelatedto5G,internetofeverything/things(IoE/IoT),cellphone-network,underwateropticalapplications&quantumcommunication[4].ThejourneyofevolutionofOWCtechnologiesspansrightfromancienttimestoFSOCoftoday.

Thisreviewpaperbeendividedintovarioussections.Section2comprehensivelyelaboratesdifferentfeaturebasedmerits&relatedmajoradvantages.Section3enumeratesmajorcontemporaryapplications.Section4dwellsuponlimitations&fewemergingmitigationtechniquesweavedinfromvarioussources.Section5bringsoutemergingtacticalmilitaryapplicationsofFSOCwhicharespecificallybasedonvarioustypesofLaserstechniquesincludinglaserweapons&remotesensingsystems.Section6listsoutvariousevolvingmilitaryapplications&utilizationinsea,air,groundandspace/UAVs.Section7spansacrossmarine,underwater&RF/Hybridsystemsbasedmilitaryapplicationsandscenarios.Section8elaboratesaboutfuturescopeandwayaheadforresearchers.Section9hasconclusion.

alongwithalmostone-tenthoftheRFantennadiameterwithrobustsecurity[5].Historically,researchworkonOWCcanbetracedtoatleast50yearsbackrelatedtospace&defenseprojects,wherein,USmilitarywassendingtelegraphsignalsbetweenvariouspointsusingsunlightenergizedequipment.

2.2.Advantages

FSOChasgarneredresearchinterestsowingtovariousinherentmerits&numerousadvantages.Itcanbedeployedrapidlytoobtainhigh-speeddataconnectivityinwirelessapplicationsattoughandremotegeographicallocations,hills&highaltitudes.RFtechnologyintheseareasisinaccessibleandopticalfiberslayingisadaunting&expensivetask.Theusageofhighlydirectional&focusedlaserbeamsresultsinlowlosstransmissionswithalargechunkofopticalpoweroutputgatheredbyRx[6].Duetotheseadvantages,researchersacrosstheglobearefieldingFSOCsystemsforshortdistancehighdataratewirelesstransmission&receptionandtheyarebeinginvestigatedforapplicationslikelast-mileconnectivity,biomedicalapplications,multi-campusnetworks,militaryaccess,MetropolitanAreaNetwork(MAN),backhaulofcellularcommunications,disastermanagementandrecoveries.Tosumup,themajoradvantagesofFSOCsystemsareaslisted[7]:-

(a)LasersusedatTxhavenarrowbeamwidthsgivinghigh-gradesecurityfeaturesunlikeRF.(b)FSOoffers2000THzBandwidth(BW)leadingtoenhancedchannelcapacity.

(c)ItisinstalledwithlowercostscomparedwithequivalentdatarateRFsystems.

(d)InFSOC,ISMbands(Industrial,scientific&medicalapplicationbands)usedareunlicensed.Nospectrumregulationareapplicableleadingtomuchlowerinitialinvestmentsandoperational/maintenancecost.

(e)FSOCtechnologyhaslowinstallationtimeframes,flexibility,rapiddeployabilityinmultiplearchitectures.Itisanenvironmentallyfriendlyandcleantechnology.

(f)FSOCishighlysecurebecauseopticalinterceptorsthattapthetransmittedbeamsarenotthereinintendednarrowpathsbetweentransceiverpairsandnospecialsecurityframeworksrequiredviewprotectedframework.

(g)FSOCuseslightweight&smallequipmentwithnoend-to-endcablingorintermediatetransducers.(h)Ithasbettertransparency/interoperability&underlyingtransmissionprotocolsarenotaltered.

(i)MeantimebetweenFailure(MTBF)ismuchbettercomparedtoRFsystems.

(j)LowerPowerconsumptionwithsmallbeamdivergenceanglewithbetterfocus.

(k)EMI/EMCresilience&electricalisolationduetothephotonicnatureofthesignal.

(l)Highlyfocusedlasersprovideleastmultipathpropagation,fading&flexibletopology.

3.MajorApplicationsofFSOC

ThefastdeployabilityoftheFSOCispoisedtorevolutionalisethetelecom&ITindustrythroughmigrationfromtower-basedsystemstomorereliableunmannedandunsupervisedcommunicationsystemsthataremoreresilient&lowerincost.Humanitarian&homelanddefenseapplicationscanberevivedfromdamagesusingtemporaryFSOnetworks.Cinema,firefightingapplications,medicalfield,telecast,broadcast,securityapplications,equipmentforLawEnforcementAgencies(LEA),powermonitoringarefewcasestudiesofcommercialFSOCprojects.Space,satellitecommunication,militaryapplications&terrestrialsystemsareseeingfastgrowthofresearchesonFSOCsystemsviewcompulsionsofbetterBERanddatarates.Byvirtueofutilizingtowersandbuildingsupport,laser-basedFSOCplatformscanbeinstalledrapidlyinminimumtimeframes,unlikeRF&satellitecommunicationequipment.MajorapplicationsofFSOCsystemsareasencapsulatedbelow[8,9]:-

(a)<u>StorageAreaNetwork(SAN)</u>.SANcanbeframedupthroughtheFSOCsystemfacilitatingintegratedandindividualdatapiecestocklevels.
(b)<u>RemoteCommunication-Outdoors</u>.Idealforremotelyoperatingorganizationsforimplementingcommunicationinabsenceoflicenses/specialpermits.
(c)<u>ReinforcementtoFiber</u>.Itprovidesreinforcementsincaseoffailureoffiber-basedsystems.
(d)<u>CellularSystemsApplications</u>.Itprovidesfastdataratestocellularmobilenetworktraffic.
(e)<u>MilitaryAccess</u>.Itisasafe,undetectable&imperceptibleframeworkconnectingzones;

SUITABILITYANALYSISOFFSOSYSTEMSINTHEMILITARYENVIRONMENT

Thischapteranalyzesthesuitabilityof FSOsystemsinthemilitaryenvironment.Whendiscussingthemilitaryenvironmentthearetwofactorsthatmustbeconsidered.First,thereisthecombatortacticalenvironment.Combatoperationshaveuniquecommunicationrequirementsthatarenotnecessarilydirectlytranslatedfromthecivilianssectorduetotheneedtooperateinremotelocationsunderveryharshconditions.Second,thereistheadministrativeenvironment.Theadministrativeenvironmentwouldcorrelatetoamajormilitaryinstallationthathasaccesstoarobustcommunicationbackbonelikefiberopticcable.Themilitaryadministrativeenvironment'scommunicationrequirements,inmanycases,translatedirectlyfromthecivilianenvironment.Thevastmajorityofthemilitaryoperatesintheadministrativeenvironment.Nevertheless,itcanquicklychangetothecombatenvironmentintheeventofanattack.Thischapterconsiderstheserequirementsandweighswhetherornot FSOisaviableoption.ThischapteranalyzeseachofthecategoriesthatwereusedtoclassifythedynamicFSOsystemsinthetaxonomypresentedinChapterII.

A.GROUND-TO-GROUND

Ground-to-groundFSOlinkscaneitherbestatic,wherebothendsofthelinkarefixed,ordynamicwhereoneorbothlinksarecapableofbeingoperatedwhilemobile.Anexampleofastaticground-to-groundlinkinthemilitaryenvironmentwouldbealinkbetweenahigherandlowerheadquartersCOC.Anexampleofadynamicground-to-groundlinkwouldbeanoperationallinkbetweentwomovingtacticalvehiclessuchasA1Abramstanks.

1.Static

Staticground-to-groundFSOhasbeenimplementedwithresoundingsuccessworldwideinthecivilianssectorandcanbeaveryviableoptionforthe

military.Thesesystemsaredesignedforestablishingnetworksforenterpriseandcampuslikeenvironments.Militarybasesfitintothiscategory.Thereisasignificantdemandforbroadbandnetworkconnectivityonandbetweenmilitaryinstallationsbothdomesticallyandabroadinbothtacticalandnon-tacticalenvironments.OfalltheavailableFSOsystems,staticsystemshavebeeninproductionthelongestandhaveprovenperformancerecords.Thesesystemscanbeinstalledquicklyandcheaplywithoutexpendingthelabortolaycableorplacepersonnelinharm'sway.Furthermore,theyareavailableasacommercialofftheshelf(COTS)technologythatcanbeacquiredthroughtheGeneralServicesAdministration(GSA)forimmediatedeployment.

a.Intra-BaseNetworking

Intra-Basenetworking,ornetworkingwithinthebase,wouldbeadirecttranslationofFSOtechnologyfromthecivilianssectortothemilitaryfornon-tacticalapplications.Mostofthebuildingsonmilitaryinstallationsareinfairlycloseproximitytoanotherbuilding,wellwithintherangeofcapableFSOsystems.Tacticalapplications,suchasnetworkingaremoteForwardOperationsBase(FOB)orPatrolBase(PB)mayrequiremoreruggedizedequipment.However,thiscouldbeachievedthroughminormodificationstotheCOTSequipment.Itshouldnotbetheintenttosetupanetworkbetweenallofthebuildingsonaninstallation,buttoincorporateFSOinareaswherethereisademandforfiber-likebroadbandconnectivityandlayingfiberopticcableisnotviableduetooperationalconstraints,cost,orsafetytopersonnel.Furthermore,anFSO-RFhybridsolutionwithasufficienttrackingcapabilityshouldbeusedtoensuremaximumlinkperformanceandavailabilityinallatmosphericconditionsandperiodsofincreasedbasemotioncausedbyheavyvehicleandaircrafttrafficaswellasshockwavesfromexplodingordnance.

ThehighdemandforbroadbandconnectivitywithinCOCswasdiscussedinChapterI,andFSOwouldbeabletomeetthatneed.However,anotherareawherethereisanextremelyhighdemandforbroadbandconnectivitywithin militaryinstallationsisonthenetworksprovidedbyMorale,Welfare,andRecreation(MWR).Whendeployed,militarypersonnelrelyveryheavilyonInternetconnectivityforcommunicationandentertainmentpurposes.Asa resultitisnotuncommonforInternetcafé'stobeestablishedbyMWR on remoteFOBsandforthelargerbasestoprovideinstallation-wideWi-Fiaccess.Thesenetworksarestressedheavilybyservicememberconductingvideoandvoicecalls,downloadingcontent,andstreamingvideo.Lowbandwidthmakescallqualitypoor,andstressestheservicememberstryingtocommunicatewithfriendsandfamily.IncorporatingFSOintothesenetworkswouldimprovetheir performance.

b.Inter-BaseNetworking

Inter-Basenetworking,ornetworkingbetweeninstallations,presentsagreaterchallengeduetotheincreasedlinkdistancerequirements.Inthecaseofnon-tacticalmilitaryinstallationsthereisahighlikelihoodofaccesstothefiberinfrastructurenegatingtheneedforFSOinter-Basenetworking.However,tacticalmilitaryinstallationsareunlikelytohaveaccesstoasecurewiredinfrastructure.Therefore,theymustbeconnectedbywirelessmeans.Tacticalmilitaryinstallationsareusuallyplacedwithinaproximitytoothertacticalmilitaryinstallationssothattheycanmutuallysupportoneanotherinthecaseofanoverwhelmingenemyattack.Thisusuallytranslatestoafewkilometersorevenlessinhighthreatenvironments.Again,thisiswellwithintherangeofcapablecommercialFSOsystems.Forlongerdistancerequirements,systemssuchasTALON,withamaxrangeof50km[2],wouldproveeffective.However,asdistanceincreasesobstaclesmaybecomeanissuewhentryingtoestablishLOSbetweenFSOunits.TechniquessuchaselevatingtheunitandcommunicationrelaymaybeusedtoincreaserangeandmitigateLOSissuesaslongassuchtechniquesaretacticallyfeasible.

c.CommunicationRelayStations

FSOsystemswouldalsobeaviableoptionforstaticground-basedcommunicationrelaystations.However,considerationshouldbegiventotherelativelyfragilenatureofanFSOlinkduetopooratmosphericsandtheLOSrequirements.Ahybridsolution,whichincorporatesFSOandRFcommunications,wouldprobablybemostviableinthecaseofcommunicationsrelay.ThiswouldaffordthestationthebandwidthandsecuritybenefitsofFSOcommunicationsinfavorableconditionsandtheavailabilityofRFcommunicationsotherwise.

d.HastilyFormedNetworks

Theabilitytorapidlyestablishandreestablishcommunicationsisparamountinmilitaryoperations.FSOandFSO-hybridsystemshavetheabilitytosetuphighbandwidthlinksextremelyquicklyviathe"flyaway"kitsdiscussedinChapterII.TheyarecapableofdoingsowithoutinterferingwithRFcommunicationsthroughtheuseofIRenergyandunlicensedradiofrequencies.Thisisidealforreestablishingcommunicationsinadisasterrelieforpostattacksituationwherethecommunicationarchitecturehasbeendamagedordestroyed.ThiscapabilityhasalreadybeenproveninthecivilianssectorfollowingtheterroristattacksontheWorldTradeCenterin2001[13].

2.Dynamic

FSOwouldproveverybeneficialinship-to-shipandship-to-shorecommunications.ThiswasdemonstratedusingtheTALONsystem[2].ThelikelihoodthatLOSbetweentwoshipsontheopenocean,ortheLOSbetweenashipatseaandashore-basedcommunicationsstationisblockedisminimalassumingpropermaneuvercoordination.Increasingthenumberofshipspotentiallywouldallowforamorerobustnetwork,againassumingpropercoordination.Withoutpropercoordination,thelikelihoodoflinkblockagegrowsasthenumberofshipsintheareaincreasesandasthecommunicationstation

ismovedfurtherinland.SomeofthechallengesencounteredinestablishingFSOlinksonsurfaceshipscanbefoundin[93].

Fornearlyeveryothertacticaloradministrativecommunicationscenarioadynamicground-to-groundFSOcommunicationlinkisnotsuitable,exceptinapplicationsthatwouldrequireveryshorttransmissionranges.ThisissimplyduetotheLOSrequirement.EstablishingandmaintainingLOSoverthegrounddynamicallywouldbedifficult,if notimpossible,especiallyinatacticalscenariowherecoverandconcealmentisrequired.Currently,mosttacticalgroundcommunicationsaredoneoverVHFfrequenciesviceUHFfrequenciesforthisveryreason.VHFfrequenciesarebetterabletomitigateobstaclesbetweencommunicationnodes.UHFisprimarilyusedforair-to-groundandair-to-aircommunicationsduetoitsabilitytotransmitoverlongerdistanceswithabetterqualitysignal.However,UHFrequiresLOS.Frompersonalexperience,UHFfrequencieshavenowherenearttheLOSrequirementsofFSO.WithUHF,itispossibletoestablishacommunicationlinkfromacoveredposition,suchasunderatreeorinsideabuilding,toanaircraft.WithFSOthiswouldnotbepossible.Nevertheless,UHFisstillconsideredunsuitableforground-to-groundcommunications.

B.AIR-TO-GROUND

Anair-to-groundFSOlinkisoneestablishedbetweenanairborneplatformandeitherastaticordynamicgroundstation.AnexampleofairtoastaticgroundlinkwouldbetheFMVfromaUAVtransmittedbacktoaCOCortotheUAVsstaticcontrolcenter.AnexampleofanairtodynamicgroundFSOlinkwouldbeaUAVtransmittingitsFMVfeedbacktoamovingvehicleorfootmobilecombattroop.

1.DynamicAirtoStaticGround

AnFSOlinkfromanairborneplatformdowntoastaticgroundstationmayprovebeneficialinbothmilitaryandciviliancommunications.LOSiseasilyobtainablefromanairborneplatformaslongasthatplatformhastheabilitytofly

atanaltitudethatcansupportanadequatelookanglefromthegroundstationtotheairborneplatform,andaslongasthegroundstationtransceiverisabletobeexposedforsignaltransmissionandreception.Thisisalmostalwaysachievablewithhighflyingfixed-wingaircraftandhigh-altitudeairships.However,lowerflyingrotary-wingedaircraftandsmallerUAVsmaynotbeabletoestablishandmaintaincontinuousLOSduetotacticalnecessityoraircraftlimitations.Thismightbeacceptableincertaincommunicationscenariosaslongasthelinkcanbequicklyreestablished.ViaLightsuccessfullydemonstratedthisapplicationofFSOwithitsMLT-20systemfromaTornadofighterjet[78].JohnHopkinsUniversityAppliedPhysicsLabandAOptixalsodemonstratedthiscapabilitybyestablishingan80Gbpslinkbetweenatetheredaerostatandagroundterminal[80].

2.DynamicAirtoDynamicGround

ThesuitabilityofanFSOcommunicationslinkfromanairborneplatformtoadynamicgroundstationismarginal.ThisisagainduetotheLOSrequirement.Whetherthegroundstationisvehicle-mountedorman-portablethereisaveryhighlikelihoodthatthemovementofthegroundstationwillinevitablyfinditinapositionwhereanobstacle,man-madeornatural,willinterrupttheLOSbetweenitandtheairborneplatform.Ahybridsolutionmightworkforthisscenario,butsize,weight,andpowermustbecarefullyconsideredespeciallyforman-portablegroundtransceivers.Forthisreason,RFsystemssuchastheGhostLinkareamoreviableoptionfortacticalscenarios.

TheGhostLinksystem,showninFigure53,isahigh-bandwidthRFsolutionforair-to-dynamic-groundlinkscurrentlybeingdevelopedbyGeneral AtomicsAeronauticalSystemsInc.

SUMMARY,CONCLUSIONANDRECOMMENDATIONS

A.SUMMARY

ThisresearchsurveyedthecurrentstateofFSOcommunicationsandthenanalyzeditssuitabilityforapplicationinthemilitaryoperatingenvironment.ThiswascompletedbyfirstprovidingathoroughbackgroundofFSOtoprovideanunderstandingoftheircapabilitiesandlimitations.Next,asystematicsurveyofcurrentFSOsystemsrelevanttomilitarycommunicationswascompleted.Fromthissurvey,amatrixofsystemcapabilitiesandlimitationswaspopulatedforeaseofreference.ThentheAnalyticalHierarchyProcess(AHP)wasintroduced,asameansofchoosinganappropriatesystem,andanexamplewasgivenofitsapplication.Next,anexperimentwasconductedusingtwosystems,establishingtwoseparatelinkssimultaneouslytogainhandsonexperienceandanunderstandingofrealisticperformanceexpectations.Finally,asuitabilityanalysisofFSOwascompletedforcommunicationscenariostypicaltothemilitaryoperatingenvironment.

Themilitaryhasanever-increasingdemandforbandwidthinaveryRFdenseoperatingenvironment.TheabilityforFSOcommunicationstosecurelytransmitverylargedataratesimpervioustoRFenergymakesitveryappealingasapossiblemilitarycommunicationsolution.

B.CONCLUSION

FSOcommunicationisaviablesolutionforcertainmilitaryapplications.ThereareundeniableperformanceadvantagesofFSOoverRFcommunicationsforcertainscenariosundercertainconditions.ThemodulatedlightofFSOiscapableofsupportingmuchlargerbandwidthsthanRFfrequencies.ThecollimatedlaserenergyofFSOprovidesLPIandLPDqualitiesmakingitveryresistanttoexploitation.FSO'simmunitytoRFinterferencemakesthesignalresilienttojammingandallowsoperationwithoutfrequencydeconfliction.Thesebenefitsaresignificantformilitary communicationswhereagreatdealofmoneyisspentonequipmentandsoftwareandeffortexpendedsecuringRFcommunicationsusuallyresultingindegradedlinkperformance.However,therearealsoconsiderablelimitationstoFSOthatpreventitfrombeingadirectreplacementforallRFcommunicationlinks.Theselimitationsareatmosphericinterference,astrictLOSrequirementandalimitedabilitytoconductareatransmissions.

TheperformanceofanFSOlinkisdirectlycorrelatedtotheatmosphericconditionswithinwhichitisoperating.Particulatesintheair,turbulenceandairdensityallimpactFSOlinkperformance.Forthisreason,itisdifficulttoaccuratelydeterminehowFSOwillperforminagivenenvironmentovertimeuntilitcanactuallybetestedinthatenvironmentforanappropriateperiodoftime.ThisisalsotrueforRFcommunications,buttheeffectthatatmosphericshaveonFSOismuchgreaterthanonRF.ThisisveryconcerningwhenconsideringFSOasacommunicationsolutionwherehigh-availabilityinallweatherconditionsisapriority.ImplementingahybridFSO-RFsolutioncanmitigatelinkdegradationinunfavorableatmospherics.However,indoingsotheLPI/LPDandRFimmunityofthelinkiscompromised.Additionally,thereareseveralpossibleapplicationsofFSOwhereadverseatmosphericswillmostlikelynotbeencountered.Theseincludespaceapplications,highaltitudeair-to-airlinksandonUAVsthatareonlycapableofoperatinginvisualmeteorologicalconditions(VMC)duetoISRsensorand/oraircraftlimitations.

TherequirementforLOSisthebiggestlimitationtoFSObecauseitwillsimplynotoperatewithoutit.EstablishingLOSintacticalsituationscanbedifficultanddangerousasitusuallyinvolveselevatingandexposingthetransceiver,theoperatororboth. DuetotheLOSlimitation,FSOsystemsaremostsuitableforstaticground-to-ground,staticground-to-air,air-to-airandspaceapplications.TheLOSrequirementmakesFSOunsuitablefordynamicground-to-groundandmarginalfordynamicground-to-airlinks,exceptinapplicationsthatonlyrequireveryshorttransmissionranges.Therearemerelytoomanyobstaclesencounteredbetweentwomovinggroundstationsand betweenamovinggroundstationandanairborneplatform.TheexceptionstothisareFSOlinksbetweensurfaceships,betweenasurfaceshipandanairborneplatformandforship-to-shorecommunications.Theopenseaprovidesarelativelyobstaclefreeenvironmentacrossitssurface.However,linksovertheoceaneventuallyfallvictimtotheLOSrequirementduetothecurvatureof the Earth.

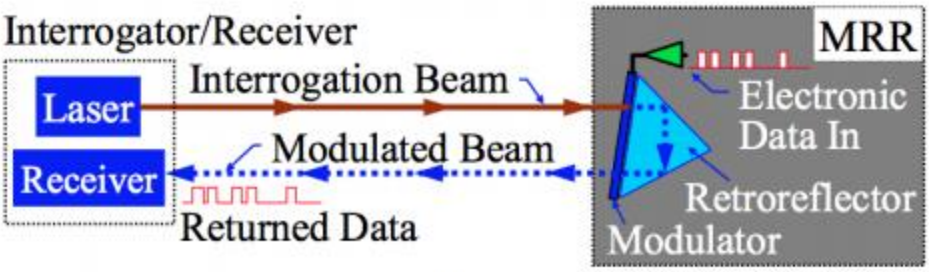
ThecollimatedlaserenergyusedinFSOcommunicationsaidsinthesecurityofthelinkthroughLPIandLPD,butisnoteffectiveindisseminatinginformationtomultiplereceivers.Theonlywaytotransmit,fromasingletransmitter,overanareaisbyincreasingbeamdivergence.Asbeamdivergenceincreases,therangeofthelinkdecreases.Currently,FSOisnotsuitableforapplicationsrequiringthedisseminationofinformationtomultipledislocatednodesfromasinglesource.

C.RECOMMENDATIONS ResearchintheareaofFSOcommunicationsshouldcontinuetobeaggressivelypursued.Thebandwidth,security,andRFimmunityqualitiesofFSOcommunicationspresenttoomanybenefitstocommunicationsinthemilitaryenvironmenttobeignored.Thisresearchshouldfocusonbetterunderstandingthecapabilitiesofcurrentsystems,improvingtheperformanceof FSOinadverseatmosphericconditions,andexploringapplicationsofFSO new systemsinthemilitarycommunicationsconstruct.

D.FUTUREWORK

1.ModulatingRetro-reflectors(MRR)

TheNavalResearchLaboratory(NRL)hasbeenconductingresearchonFSOsince1998.Someoftheirrecentworkhasbeenintheareaofmodulatingretro-reflectors(MRR).OneofthecurrentlimitationstoastandarddynamicFSOlinkisthataturret/gimbalisrequiredatbothendsofthelink.Thisaddsconsiderablecomplexitytothedesignandincreasesthecost,size,weightand power(CSWaP)requirementsofthesystems.AnMRR,picturedinFigure55,isverysmallandalleviatesCSWaPrequirementsforoneendoftheFSOlink [97].



(a)

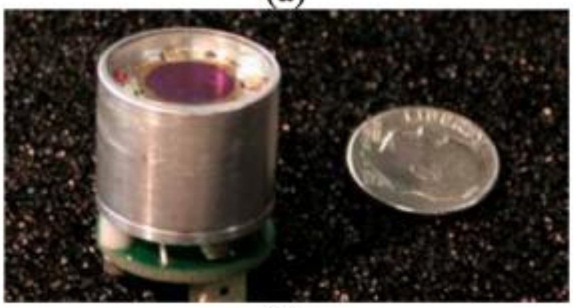

(b)

Figure55.A(a)MRRsystemdiagramand(b)MRRtransmitter,from[97].

ThisispotentiallyaveryvaluableapplicationofFSOtechnology,especiallyinairborneapplicationswhereCSWaPrequirementstendtobemorestringent.TheNRL'sworkonMRRshasbeenpublishedin[97].TheCommand,Control,Communications,andIntelligenceDivisionoftheAustralianDefenceScienceandTechnologyOrganisationexpandedontheworkdonebytheNRL.Thatworkcanbefoundin[98].FutureworkwithMRRsshouldfocusonthefollowingareas:

(1)ValidateinterrogationofanairborneMRRbyaground-basedFSOsystem.

(2)ValidatetheabilityofanairborneMRRtosimultaneouslymodulatetwoindependentinterrogationsignalsfromtwodislocatedgroundbasedFSOsystems.

B.5CONCLUSIONANDRECOMMENDATIONS

TheLaserFiresystemisnotcurrentlyreadyfordeploymentnorwoulditbeaviableoptionfordynamiclinksinitscurrentconfiguration.Thereareseveralissuesthatneedtobeaddressedbeforethesystemcouldbeusedinanoperationalsetting.First,theissueofoverheatingmustbeaddressed.Second,linkacquisitionmustbespedup.Third,thesizeofthesystemmustbereduced.Finally,datarateshouldbemadeadjustableallowingforoptimizingthetransmissionrateaccordingtothelinkperformanceasmeasuredbysignal-to-noiseratioorpacketloss.

ThedesignoftheLaserFireV3needstobeimprovedtoallowforgreaterdissipationofheatfromelementsinsidethemodemandtransmitterboxes.Currently,theboxesarecompletelysealed.Theiraluminumconstructionprovidessomereliefduetoitsrelativelyhighconductivity,howeverthisaloneisnowherenearsufficient.Ondayfouratthehillsite,thetransmitterandmodemwereplacedintheshadeandinwell-ventilatedpositions.Bothwerecooltothetouchontheoutsideofthebox.However,themodemstillshutdownduetooverheating.Uponinspectionitwasfoundthatthenetworkcardinsidethemodemwastheonlyelementhottothetouch.

Initiallinkacquisitionisafairlytimeconsumingprocess.Itrequirestheoperatortomanuallyalignthetwounitsandtheninitiateanautomatedsearchpattern.Oncethepatternisinitiatedtheamountoftimetoacquirevariesdependingonhowwelltheunitswerealignedmanuallyandthesystem'ssearchconfiguration.Therewereseveralinstanceswherethesearchpatternfailedtoidentifytheoppositeendofthelinkandhadtoberestarted.Additionally,duringtestingtherewereseveralinstanceswheretheLOSofthelinkwasinterruptedeitherbysomeonewalkingthroughthebeamspathoracardrivingthroughit.Innearlyeveryinstancethiscausedthelinktodropandsentthesystemintoanautomaticreacquisitionsearchpattern.IncorporatingtheuseofGlobalPositioningSystem(GPS)coordinates,increasingthesearchareathroughadjustablebeamdivergence,andbyimplementinganinterrogationprotocolthat allowsthesystemtoidentifyithasestablishedlinkwiththecorrectunitmayhelpinspeedinguptheacquisitionprocess.Adynamicapplicationwouldnotbepossiblewithoutnearinstantaneouslinkreacquisition.

Inordertoincreaselinkqualitytheusershouldhavetheabilitytodialbackthebandwidth.Ifahighrateofpacketlossisexperiencedata1Gbpsbandwidth,adjustingthebandwidthto100Mbpsmayimprovelinkquality.Abandwidthof100Mbpsissufficientfornearlyeveryapplicationandgreaterthanmost RFoptions.

ItisrecommendedtocontinueresearchanddevelopmenteffortswithSpacePhotonicsInc.aswellasexploringotherFSOsystems.

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